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BRISTOL BAY ESCAPEMENT GOALS FOR 1966 RED SALMON RETURN

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TABLE OF CONTENTS

	Page No.
List of Tables	1
List of Figures	2
Introduction	4
Methods of Analysis	9
1966 Bristol Bay Prediction	13
Escapement Goals by River System	
Wood River	15
Igushik River	24
Nuyakuk River	28
Snake, Nushagak-Mulchatna and Togiak Rivers	33
Kvichak River	37
Naknek River	52
Branch River	58
Egegik River	59
Ugashik River	64
Summary Table of 1966 Bristol Bay Escapement Goals	70
Bibliography	71
Appendix	73

LIST OF TABLES

Table Number	Page Number	Table
1	13	1966 Bristol Bay Forecast by River System.
2	18	Wood River Red Salmon Smolt Production Data, 1949-62.
3	19	Wood River Marine Survival of Red Salmon Smolt, 1954-62.
4	25	Igushik River Red Salmon Escapement-Return Data, 1952-60.
5	30	Nuyakuk River Red Salmon Escapement-Return Data, 1952-60.
6	36	Snake, Nushagak-Mulchatna and Togiak River Escapement, 1951-65.
7	45	Kvichak River Red Salmon Production Data, 1952-62.
8	46	Naknek-Kvichak District Red Salmon Returns and Japanese High Seas Catches, 1956-65.
9	54	Naknek River Red Salmon Smolt Production Data, 1954-62.
10	55	Naknek River Red Salmon Marine Survival, 1956-62.
11	58	Branch River Red Salmon Escapement-Return Data, 1955-60.
12	61	Egegik River Red Salmon Escapement-Return Data, 1944-60.
13	66	Ugashik River Red Salmon Smolt Data, 1955-62.
14	67	Ugashik River Red Salmon Marine Survival, 1958-62.
15	70	1966 Bristol Bay Red Salmon Escapement Goals by River System

LIST OF FIGURES

Figure Number	Page Number	Figure
1	5	Theoretical production curve showing red salmon production as a function of parent spawning.
2	8	Approximate location of catch sampling and escapement counts for Bristol Bay red salmon run, 1966.
3	20	Wood River red salmon escapement-smolt production relationship, 1949-62.
4	21	Wood River red salmon escapement-relative production relationship, 1949-62.
5	22	Wood River Age I red salmon smolt length versus numbers of smolt in outmigration.
6	23	Average yearly commercial catch of red salmon for five-year periods, Nushagak District, 1896-1965.
7	26	Igushik River red salmon escapement-return relationship, 1952-60.
8	27	Igushik River red salmon escapement-relative production relationship, 1952-60.
9	31	Nuyakuk River red salmon escapement-return relationship, 1952-60.
10	32	Nuyakuk River red salmon escapement-relative production relationship, 1952-60.
11	47	Naknek-Kvichak district red salmon catch, 1893-65.
12	48	Kvichak River red salmon escapement-smolt production relationship, 1953-62.
13	49	Kvichak River red salmon escapement-return relationship, 1952-60.
14	50	Kvichak River red salmon parent escapement and percent production of Age II smolt by year, 1952-62.
15	51	Kvichak River red salmon escapement-relative production relationship, 1952-60.
16	56	Naknek River red salmon escapement-smolt production relationship, 1954-62.
17	57	Naknek River red salmon escapement-relative smolt production relationship, 1954-62.

LIST OF FIGURES (Cont.)

Figure Number	Page Number	Figure
18	62	Egegik River red salmon escapement-return data, 1944-60.
19	63	Egegik River red salmon escapement-relative production data, 1944-60.
20	68	Ugashik River red salmon escapement-smolt production relationship, 1955-62.
21	69	Ugashik River red salmon escapement-relative production relationship, 1955-62.

APPENDIX

A-1	73	1966 Nushagak Commercial Fishing District
A-2	74	1966 Togiak Commercial Fishing District
A-3	75	1966 Naknek-Kvichak Commercial Fishing District
A-4	76	1966 Egegik Commercial Fishing District
A-5	77	1966 Ugashik Commercial Fishing District

1966 BRISTOL BAY RED SALMON (*Oncorhynchus nerka*) ESCAPEMENT GOALS

INTRODUCTION

This report is the first in a series of annual reports designed to present the Bristol Bay red salmon escapement goals as established by the Division of Commercial Fisheries of the Alaska Department of Fish and Game. The following participated in the preparation of this report: Kenneth R. Middleton, Michael L. Nelson, Steven Pennoyer, Frank J. Ossiander and Melvin C. Seibel. Mr. Seibel edited and assembled the final report.

To manage a salmon run for maximum sustained yield, a certain portion of each year's red salmon return must be allowed to pass through the commercial fishery and reach the spawning grounds to provide for returning runs in future years. As the managing agency for the Bristol Bay red salmon stocks, the Alaska Department of Fish and Game is responsible for insuring that a proper percentage of each year's run is allowed to spawn. What size of escapement constitutes a "proper" percentage of the run will depend on several factors.

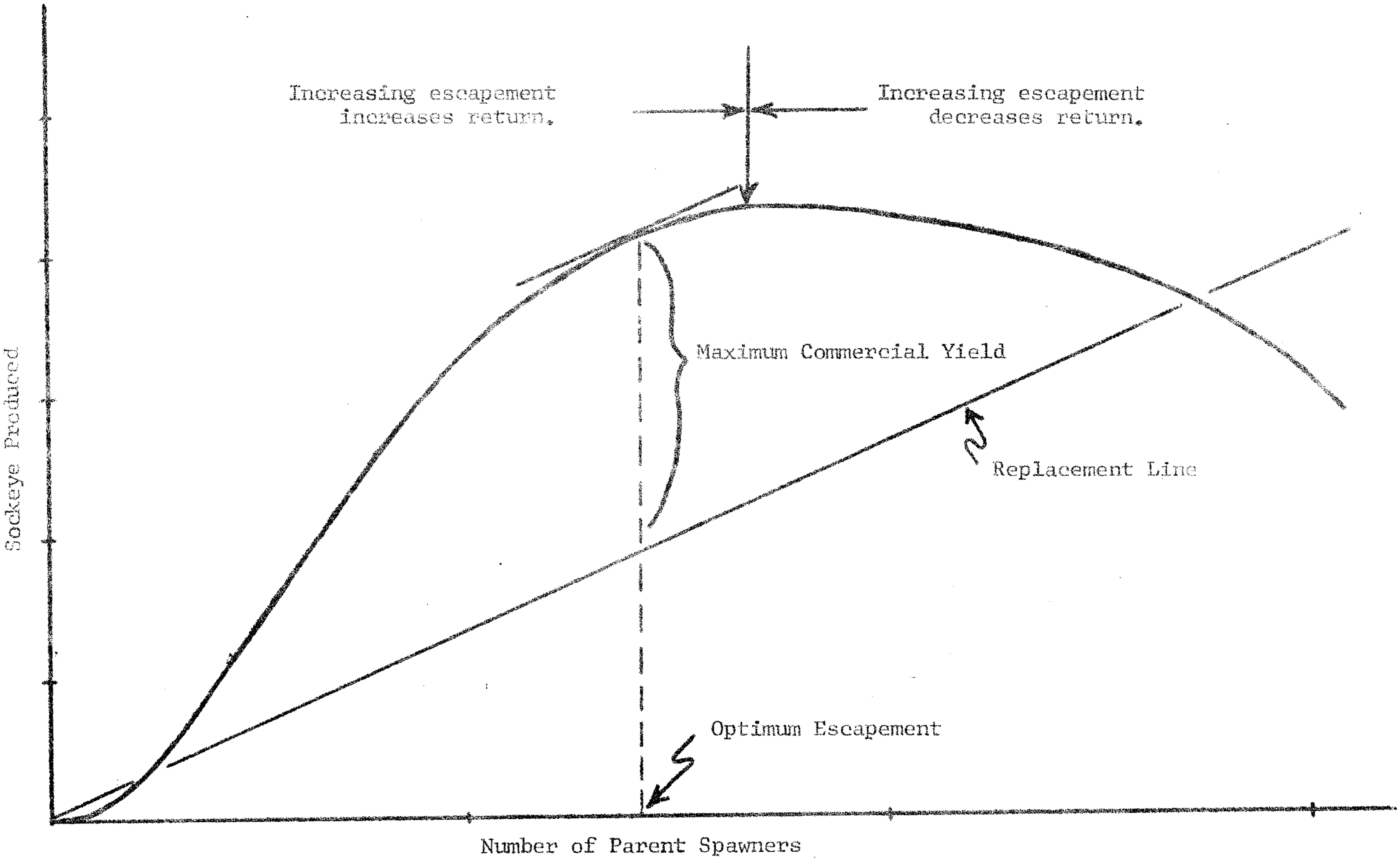
A.) Determination of Optimum Spawning Populations

One of the most important concepts in modern management of salmon stocks is that of "optimum escapement". Optimum escapement may be defined as that number of spawning fish which produces the maximum <u>sustained</u> yield (i.e. catch). Increasing the size of the spawning population beyond a certain point will not necessarily increase the size of the yield or even the size of the total return. Figure 1 shows one theoretical production curve in which the production or return is expressed as a function of escapement. The replacement line represents the level of production required for a run of salmon to reproduce itself. For a given level of escapement, the difference between the actual production curve and the replacement curve represents the allowable commercial catch if the population is to be maintained at that level. For the level(s) of escapement at which the actual production curve and the replacement line intersect, the entire return must be allowed to spawn if the population is to be maintained at that level. It is possible that the true production curve falls below the replacement line. In this case (generally occurring at extremely low or high escapement levels), the spawning population does not replace or reproduce itself.

The curve can be divided into two parts; the first part (to the left of the peak) indicating <u>increased</u> production with increased escapement and the second part (to the right of the peak) indicating <u>decreased</u> production with increased escapement. The limitation on production is imposed by limitations in ecological factors such as spawning areas, rearing areas, food, etc. that restrict the number of salmon a system can support.

It is apparent that for a population exhibiting this type of reproduction, the optimum escapement will fall somewhere in the first part of the curve. Furthermore, the optimum escapement will not be that escape-

Figure 1. THEORETICAL PRODUCTION CURVE SHOWING SOCKEYE PRODUCTION AS A FUNCTION OF PARENT SPAWNERS



ment which produces maximum return as relatively large increases in escapement near, and to the left of the peak of the curve may result in relatively small increases in production. Note that if the portion of the curve lying to the left of the peak rises sharply, then only slight decreases in the escapement (below the optimum escapement level) may result in drastic decreases in the return. For systems exhibiting this type of production trend, a safety factor is necessary. This safety factor consists of an escapement goal slightly higher than the indicated optimum escapement with the additional increase in the escapement goal depending on 1.) the amount of variability in return experienced in the past as a result of natural and high seas fishing mortalities, and 2.) the amount of variability experienced in managing the inshore fishery to obtain the desired escapement. The risk (in terms of reduced commercial catch) is much greater for an over-fished population than for an under-fished population.

Optimum escapement does not necessarily imply a single escapement size which will apply to every year under all conditions. The optimum escapement for a given stock may very well change with changing ecological conditions. Populations exhibiting cyclic dominance may require greater escapements during the dominant year(s) than for the subdominant years, whereas production data from populations having relatively consistent production may indicate a single optimum escapement size.

In the following report, it is to be understood that references made to optimum escapement for a given system are based only on present available data and are not intended to provide final answers. As new data is added to our present information, new and possibly different production trends may develope which indicate optimum escapements different from those given in this report. This is especially true for those systems for which only limited production data is available.

B.) Size of the Predicted Return and Requirements of the Commercial Fishery

Escapement goals for a given year cannot be established until a prediction of the returning run has been made. There are two reasons for this. First, although past production data may indicate an optimum escapement for a given stock, the desired escapement goals must be set relative to the salmon available in a given year. In some years the entire return may not equal the indicated optimum escapement. Second, except in very extreme cases in which a stock is in danger of reaching too low a level, the commercial fishery cannot be closed entirely or restricted too severely, i.e. a certain portion of the return must be allowed to be taken commercially for the economic welfare of the fisherman and the salmon industry.

C.) Past Trends of Escapements to a Given System

A third aspect that must be taken into consideration when establishing escapement goals for a given river is the trend of recent spawning populations to that system. This is especially important for those systems for which no definite production curve has been determined. Although final return data will not be complete for the most recent brood years, if escapements have been excessively low (and/or decreasing), the management philosophy would be to increase the escapements to these systems. Therefore, for systems which have been experiencing a recent significant decline in spawning populations, the portion of a return allowed for commercial harvest must be decreased, thus increasing the number of salmon allowed to reach the spawning areas.

The basis for establishing escapement goals is, therefore, a combination of conservation and economic considerations, with the conservation of the salmon stocks being the primary consideration for the management biologist.

The Bristol Bay sockeye fishery consists of five commercial fishing districts (cf. Appendix) and ten major spawning areas (cf. Figure 2). Counting towers located in the clear water portion of the rivers provide estimates of the escapements to each of the major rivers. Escapement to a number of minor spawning areas which do not have counting towers must be estimated on the basis of aerial and ground surveys of the spawning grounds.

In the following report, for each major river system, the 1966 predicted return, the desired escapement goal and the corresponding escapement range are given. The escapement range is given for two reasons:

A.) Insufficient Control Over Escapement as a Result of Insufficient Data

Although the Alaska Department of Fish and Game has the authority to issue emergency regulations (thereby limiting commercial fishing time), this alone does not insure achievement of desired escapement goals. At least four factors add to the difficulty of managing a commercial fishery to obtain desired escapement goals:

1.) Inadequate Data Regarding Time and Pattern of Entry

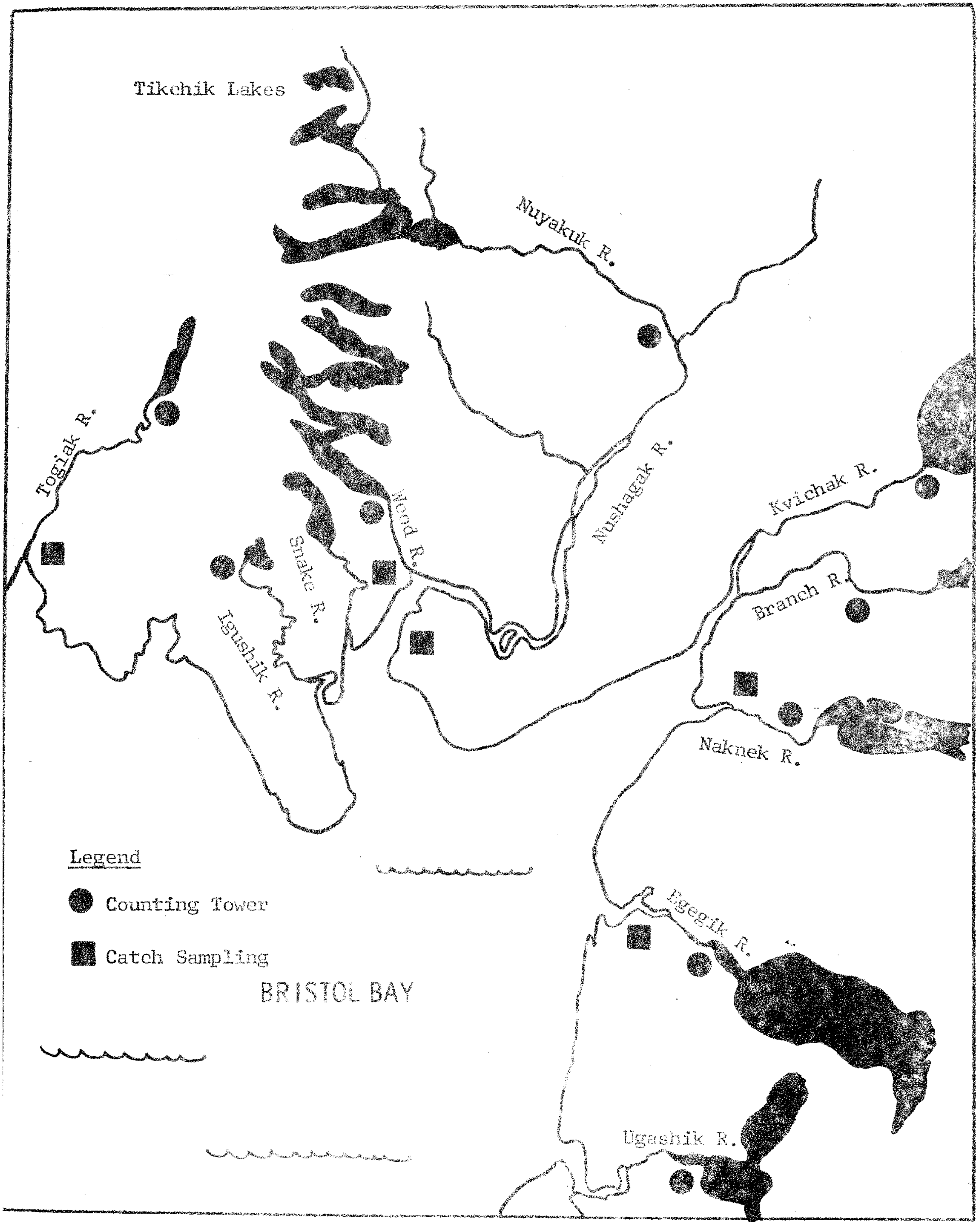
Yealy variations in the time and pattern of entry of salmon migrating into Bristol Bay affect the accuracy with which the run can be proportioned into catch and escapement. Although some information is obtained from high seas sampling and inshore test fishing, it is insufficient to predict exactly what stage the run is in. This becomes increasingly important when the variability of prediction success is considered.

2.) Lack of Immediate Escapement Data

Once the salmon have passed through the commercial fishery they can be considered as escapement. However, an estimate of the number of these fish is not available until after the salmon have passed the inside test fishing (Seibel, 1965) areas (for three of the systems), or until they have reached the clear water sections of the rivers where they can be estimated by aerial survey. These estimates are not available until several days after the fish have passed through the commercial fishery, during which time more fish are moving into the fishing areas and decisions must be made regarding allotment of fishing time. Final enumeration of the escapement is made at the counting tower.

Figure 2

APPROXIMATE LOCATIONS OF CATCH SAMPLING AND COUNTING TOWERS
BRISTOL BAY, 1966



3.) Fishing on Mixed Stocks

In two of the fishing districts, viz. the Naknek-Kvichak and the Nushagak districts, salmon from several different rivers enter the district together and hence must be fished as mixed stocks. The problem encountered here is accentuated when differential harvest rates are required to obtain the desired escapements for each of the systems.

4.) Increasing Efficiency of the Inshore Fishery

With the increase in gear and the efficiency of this gear, the harvesting potential of the fishing fleet increases too. In 1965, 1.6 million sockeye were taken in the Naknek-Kvichak district in a single 12-hour period, emphasizing the tremendous harvest potential of the fishing fleet and the consequent difficulty with which the number of salmon taken commercially can be controlled.

B.) Variability of Predictions

The accuracy with which returning runs can be predicted depends first on the accuracy with which the abundance of sockeye can be measured at some earlier life stage, second on the variability of mortalities (both natural and high seas fishing) acting on the sockeye population between the time a measure of abundance is obtained and when they return to Bristol Bay, and third on the accuracy with which the rate of maturing (i.e. the age at which the salmon return from the ocean) can be predicted. Since past predictions have achieved only a limited degree of success, an escapement range is established within which the escapement goal can be adjusted if the actual return varies moderately from the predicted return. If the returning run differs substantially from the predicted return, generally the escapement or commercial catch will vary substantially from what was anticipated.

With the above considerations in mind, desired escapement ranges are established which reflect the variability inherent in the present day management of the commercial fishery. Therefore, unless the returning run is substantially different from the predicted return, the returning run can generally be managed in such a manner as to obtain an escapement within the desired escapement range.

METHODS OF ANALYSIS

Production from a given escapement can be expressed in terms of eggs, fry, smolt or adults. Relative production from one stage to another will be dependent on ecological conditions that result in variable mortalities at these different stages. The particular stage in the salmon life history at which production is measured will depend on 1.) the feasibility of accurately estimating the abundance of fish at that stage, and 2.) the degree with which density dependent mortalities affect the salmon after the stage at which the production has been measured. Production should be measured at the earliest possible life stage after which no (or few) density dependent mortalities occur to minimize the effect of variable extrapensatory (i.e. density independent) mortalities on the production trends of the salmon stocks. Extrapensatory mortalities occurring prior to the stage at which production is measured could in fact prevent the accurate description of the production trends of the population.

The following notation is used in the remainder of the report:

E = spawning population, i.e. escapement,

S = smolts produced,

R = adult return,

S'= relative smolt production, i.e. smolts produced per parent spawner,

R'= relative adult production, i.e. adult return per parent spawner,

N = sample size,

e = base for natural logarithms,

ln= natural logarithms,

a,b = parameters to be determined.

Salmon production in the Bristol Bay systems is measured at one of two stages in the life history; either the smolt stage or the adult stage. For the purpose of mathematically describing the reproduction of a given sockeye population, two production equations were considered:

$$R = a E e^{-b E} \qquad (1)$$

and

$$R = a E^2 e^{-b E} \qquad (2)$$

(If production is measured in terms of smolt, then R is replaced by S.)

Equation (1) is the "standard" Ricker (Ricker, 1958) production curve. Ricker refers to recruitment (i.e. smolt or adult return) at some stage "after density-dependent mortality ceases". There is substantial evidence that the major density-dependent mortalities occur prior to the smolt stage, or at least prior to marine life. In their studies on the Adams River sockeye stocks, Ward and Larkin (Ward, Larkin, 1964) conclude that " in the marine and adult stages the overall effect of mortalities seems to be independent of population size". In particular, the data from the Naknek and Ugashik rivers indicates density-dependent mortalities either do not occur in the marine enviroment, or they are overbalanced by the predominant extrapensatory mortalities.

Measuring production in terms of smolts produced rather than adults produced has the advantage of eliminating the effect of variable estuarine and ocean mortalities, the variability of proportioning commercially harvested (both high seas and inshore) salmon to individual systems when these salmon have been harvested from mixed stocks, etc.

Some characteristics of Eq. (1) in terms of salmon production are:

a.) If there is no escapement, there is no production, i.e. the curve passes through the origin.

b.) For very high escapement levels, production decreases asymptotically, implying that even very large escapements will reproduce to some extent.

c.) Relative production decreases continuously as escapement increases.

Eq. (2) differs significantly from Eq. (1) in only one respect, viz. the third characteristic listed above. For Eq. (2) the poorest relative production (i.e. return or smolt per spawner) occurs at the lowest escapement levels with the maximum relative production occurring at some intermediate escapement level. A population which reproduces in the manner described by Eq. (1) will exhibit maximum relative production at the lowest escapement levels.

The phenomena described by Eq. (2), viz. a reduced rate of relative production (i.e. depensatory (Neave, 1953) mortalities or mortalities inversely proportional to spawning density) for the lower spawning densities may be a result of predation, competition of other species, poor spawning efficiency (inability of salmon to become paired up on the spawning grounds), or a combination of these and other similar factors. This phenomena of depensatory mortality was discussed by Neave (Neave, 1953) in his study of pink salmon (O. gorbuscha) populations in British Columbia.

Although we would expect all three types of mortalities (compensatory, depensatory and extrapensatory) to act to some degree on the populations, in general, the overall trend represents one of the three. In Eq. (2), depensatory mortalities predominate up to a certain spawning density (viz. that density for which maximum relative production occurs), then beyond that point compensatory mortalities predominate.

Preliminary analysis of escapement-return and escapement-smolt production data indicated that in general, Eq. (2) provided a better fit (based on residual sum of squares) than did Eq. (1). For this reason, Eq. (2) is used in this report to describe the production trends of the Bristol Bay salmon.

To determine the parameters a and b in Eq. (2), Eq. (2) was rewritten in the form:

$$\ln (R/E^2) = \ln a - b E \qquad (3)$$

which is linear in ln (R/E^2) and E. Usual regression methods can then be applied to determine ln a and -b and, hence, a and b.

Although regression methods were used to determine the parameters a and b in Eq. (2), the linear correlation coefficient r is not used as a measure of the degree of linearity between the variables ln (R/E^2) and E. It is very unlikely that the random variables ln (R/E^2) and E are bivariate normal, a requirement that must be met if r is to represent an "appropriate estimate" (Snedecor, 1950) of the population coefficient ρ. Instead, the coefficient of determination r^2 is given in the instances where Eq. (2) is used to describe the production of a given stock. A useful interpretation of r^2 is that it represents the fraction of the sum of squares (of the deviations of ln (R/E^2) from the mean) that can be attributed to the independent variable E, i.e. to the regression. Since r^2 may take on values between zero and one, values of r^2 near 1 indicate a good fit of the data to the straight line.

It may be readily shown that for Eq. (2), the escapement which produces maximum catch is that value of E, say E_o, for which the slope of the curve at E_o is 45^o. Expressing this mathematically, we have the optimum escapement E_o is such that

$$dR/dE\Big|_{E=E_o} = 1.$$

As is the case with Eq. (1), E_o cannot be determined directly by algebraic methods. The usual approach is to approximate E_o by graphically determining the point on the curve where the slope is 45^o. In the case where smolt production is used, a slightly different approach must be used and this method is described in the Wood River section where it is first used.

1966 BRISTOL BAY FORECAST

Table 1 gives the final forecast by river system of red salmon returning to Bristol Bay in 1966. The anticipated return is composed of 48.4% 2-ocean and 51.6% 3-ocean sockeye.

The forecasted returns given here include any sockeye that might be taken by the high seas fishery. In view of the lack of any new restrictions to reduce or eliminate the high seas fishery, the inshore return to each system will be somewhat less than the forecasts given in Table 1. Furthermore, this reduction in inshore return will be reflected mainly in the inshore harvest (summarized in Table 15) as the inshore return must be managed to obtain the most desirable escapements.

Although the forecasted 1966 return will be similar in age structure to the runs of 1957 and 1961, it will be slightly larger in magnitude. The returns of 1957 and 1961 are summarized below: (No. of fish in millions.)

Table 1. 1966 Bristol Bay Red Salmon Forecast by River System
(Number of Fish in Thousands)

River System	2-ocean Return	3-ocean Return	Total Return
Wood River	1,950	466	2,416
Igushik River	139	414	553
Nuyakuk River	37	204	241
Snake River	7	4	11
Nushagak & Mulchatna R.	2	45	47
Total Nushagak	2,135	1,133	3,268
Togiak River	91	222	313
Togiak Tributaries 2/	--	---	30
Kulukak River 2/	--	---	10
Total Togiak	--	---	353
Kvichak River	10,622	11,016	21,638
Branch River	104	87	191
Naknek River	515	1,352	1,867
Total Naknek/Kvichak	11,241	12,455	23,696
Egegik River	1,338	1,837	3,175
Ugashik River	366	864	1,230
Total Bristol Bay	16,005	17,060	33,065

1/ Data Source: Ossiander, 1966

2/ Forecasts based on average total returns to these systems.

Year	Total Run	Percent 3-ocean	Total Harvest (Inshore + High Seas)	Inshore Harvest	Percent of Total Harvest Taken by High Seas Fishery
1957	21.7	75.1	13.9	6.3	54.7
1961	26.3	70.1	18.3	11.9	35.0

The fact that a large percentage of the 1966 return will be large 3-ocean fish which tend to swing farther westward before entering Bristol Bay (making them more available to the high seas fishery) indicates that the 1966 return could be seriously affected by the high seas fishery. Unless there is a very substantial reduction in effort, this fishery could account for a 35-55% reduction in the total allowable inshore harvest. This decrease in potential inshore harvest would be most seriously felt in the Naknek-Kvichak district where 71.7% of the total 33.1 million return and 78.0% of the 21.6 million harvest is expected. Although the other districts would not be expected to contribute to the high seas harvest in the same magnitude as the Naknek-Kvichak district, their returns would be reduced proportionately depending on the percentage of 3-ocean sockeye in their returns.

ESCAPEMENT GOALS BY RIVER SYSTEM

WOOD RIVER

1966 Prediction: 2,416,000

1966 Escapement Goal: 900,000

1966 Escapement Range: 700,000-1,100,000

Smolt studies conducted since 1951 on the Wood River system have provided an index of abundance of the yearly smolt outmigrations. On the basis of scale analysis and length frequency data the age composition of the yearly smolt outmigration has been determined and hence the smolt production by brood year. Table 2 shows brood year escapement, smolt production and relative production for the years 1949-62.

Equation (2) was fitted to the escapement-smolt data in the manner described in the Methods of Analysis section. The following equation was obtained:

$$S = 0.0011\ E^2\ e^{-0.0013\ E} \qquad (4)$$

A coefficient of determination $r^2 = 0.687$ indicates that 68.7% of the sum of squares of the deviation of $\ln S/E^2$ is explained by the regression. Figures 3 and 4 show the production and relative production respectively plotted against escapement and the curves fitted to this data.

To determine the slope of the replacement line when production is expressed in terms of smolt, the average marine survival rate (expressed in terms of adult return per smolt (or smolt index) is calculated. The reciprocal of the survival rate is then the slope of the replacement line. Note that for a given escapement, the smolts produced, as determined by the replacement line, multiplied by the average marine survival (reciprocal of the slope of the replacement line) is equal to that given escapement.

The maximum sustained yield occurs at that level of escapement, say Eo, for which the difference between the production curve and replacement line is maximum. Furthermore, it may be shown that Eo is such that the slope of the production curve at Eo is equal to the slope of the replacement line. As mentioned previously, the value of Eo is approximated by graphic methods.

On the basis of an average "7,400 returning adults per smolt index point" survival rate (refer to Table 3), an optimum escapement of approximately 1,100,000 is indicated.

Note that the brood years 1951-54 show significantly greater relative production than the following years. If the escapements for these years were underestimated and/or the smolt outmigration were over estimated, this would account for these obvious differences. If in fact the years 1951-54 did produce at lower levels, the optimum escapement would be somewhat larger than indicated.

Spawning ground studies (USFWS Manuscript Report on file, 1964)[1/] have indicated a maximum observed spawning population of 2,844,000 sockeye for the Wood River system. This figure was obtained by summing the maximum observed spawning populations for all areas in the Wood River system. The potential spawning area capacity of the Wood River system has been estimated in excess of 30 million spawners, however, the highly variable rate of utilization of spawning grounds in different years and the reliability of the estimates of potential beach spawning area make this estimate unrealistic as far as an actual spawning population is concerned.

Since 1951, escapements to the Wood River system have averaged 813,883 with a maximum escapement of 2,209,266 sockeye in 1959.

On the basis of the estimated spawning ground capacity, observed maximum spawning populations and the indicated optimum escapement of 1,100,000 spawners, a limited nursery potential in the Wood River is indicated. Figure 5 shows the length of Age I smolt plotted against the number of index points in the outmigration. Only Age I smolt are considered since on the average the outmigration consists of 89.3% Age I smolt as opposed to 10.7% Age II smolt. A slight trend is apparent for reduced growth with increased size of outmigrations. However, the effect of changing sockeye densities on smolt size may be partially masked by the effect of changing competitor (stickleback) densities. The phenomena of inter- and intra-specific competition in the Wood River system is discussed by Burgner (Burgner, 1962).

The 1966 escapement goal of 900,000 is slightly less than the indicated optimum escapement. The return in 1966 will result primarily from the 1962 escapement of 874,000 of which 73% was concentrated in two of the five Wood River Lakes. Since the spawning ground distribution in 1966 is expected to be similar to that of 1962, escapement in excess of 900,000 could result in over-crowding of Lakes Nerka and Beverly.

There is substantial evidence that the Nushagak district sockeye historically produced at a higher level than at present. Since the Wood River stocks represents a large portion of the Nushagak run (60%, 78% and 67% in 1965, 1964 and 1963 respectively), it is suspected that the Wood River stocks produced at proportionately higher levels. Figure 6 shows average yearly commercial catches for 5-year periods from 1896-1965. The commercial catch reached an all-time high for the period 1901-1905 when a yearly average of 5,836,000 sockeye was harvested. Of the fourteen 5-year periods, 6 of the periods exhibited average yearly commercial catches in excess of 3 million sockeye. The period 1951-55 was the

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[1/] Permission to use material in this report received from W. Hartman, personal conversation, June 2, 1966.

lowest period with a yearly average harvest of 591,000. Second low period was 1961-65 with a yearly average harvest of 1,006,000.

Since the available production data is for years of apparently reduced production levels, the level of optimum escapement may very well be under estimated.

On the basis of the historically higher levels of production, the Wood River and other Nushagak stocks will be managed so as to obtain generally higher levels of escapement than in the past in an attempt to return these stocks to their original levels of production.

In view of the 1966 prediction of 2,416,000 sockeye, the escapement goal of 900,000 represents a 62.7% allowable harvest.

Table 2. Wood River Red Salmon Productions Data,[1] 1949-62

Brood Year	Escapement[2]	Smolts Produced[3]	Smolt Per Spawner x10
1949	101	8.9	0.9
1950	452	112.9	2.5
1951	458	300.6	6.6
1952[5]	227	424.6	18.7
1953	516	287.8	5.6
1954	571	288.0	5.0
1955	1,383	214.4	1.6
1956	773	154.0	2.0
1957	289	57.9	2.0
1958	960	258.3	2.7
1959	2,209	507.3	2.3
1960	1,016	166.7	1.6
1961	461	78.9	1.7
1962	874	351.9	4.0

1/ Data source: Nelson, 1966

2/ Escapement in thousands.

3/ Smolts produced expressed in index points. One index point = 1,700.34 smolt captured in index fyke net. Adjusted 2-hour index used.

4/ Smolt per spawner expressed in smolt index points per thousand spawners.

5/ Omitted as outlier on the basis of relative production.

Table 3. Wood River Red Salmon Smolt Marine Survival 1/, 1954-62.

Year of Outmigration	Smolt Index 2/	Adult Return 3/	Marine Survival 4/
1954	438.6	1,731	3.9
1955	221.7	761	3.4
1956	326.6	1,577	4.8
1957	165.5	4,812	29.1
1958	230.9	1,996	8.6
1959	60.5	427	7.1
1960	223.3	2,503	11.2
1961	518.7	1,512	2.9
1962	177.6	3,181	17.9

Geometric mean survival = 7.4

1/ Data sources: a) Nelson, 1966
b) Ossiander, 1966

2/ One index point = 1,700.34 smolt captured in index fyke net.
Adjusted 2-hour index used.

3/ Return given in thousands of fish.
Includes estimated high seas catch.
Includes only 2- and 3-ocean fish.

4/ Expressed in thousands of returning adults per smolt index point.

Figure 3. Wood River Red Salmon Escapement - Smolt Production Relationship, 1949-62

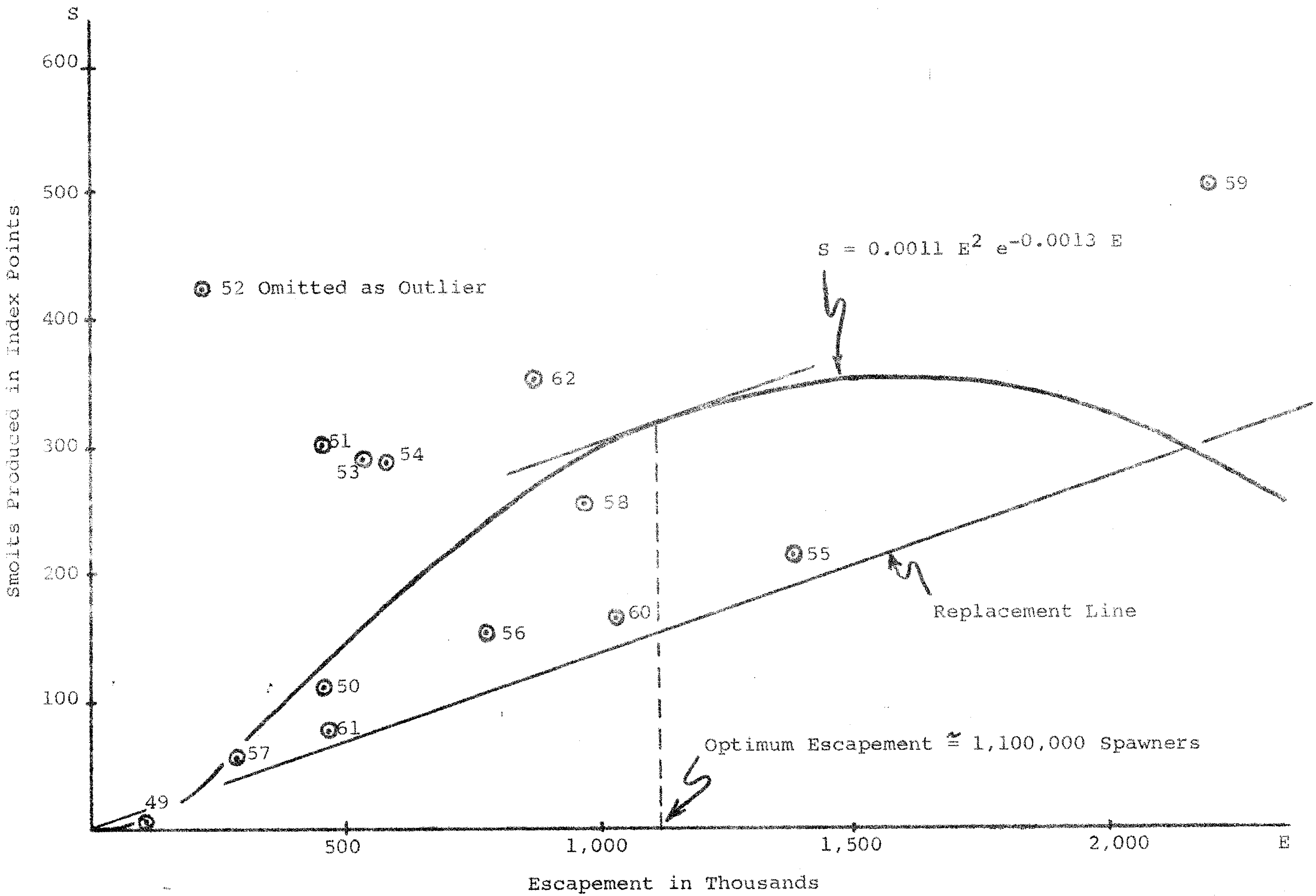


Figure 4. Wood River Red Salmon Escapement - Relative Production Relationship, 1949-62

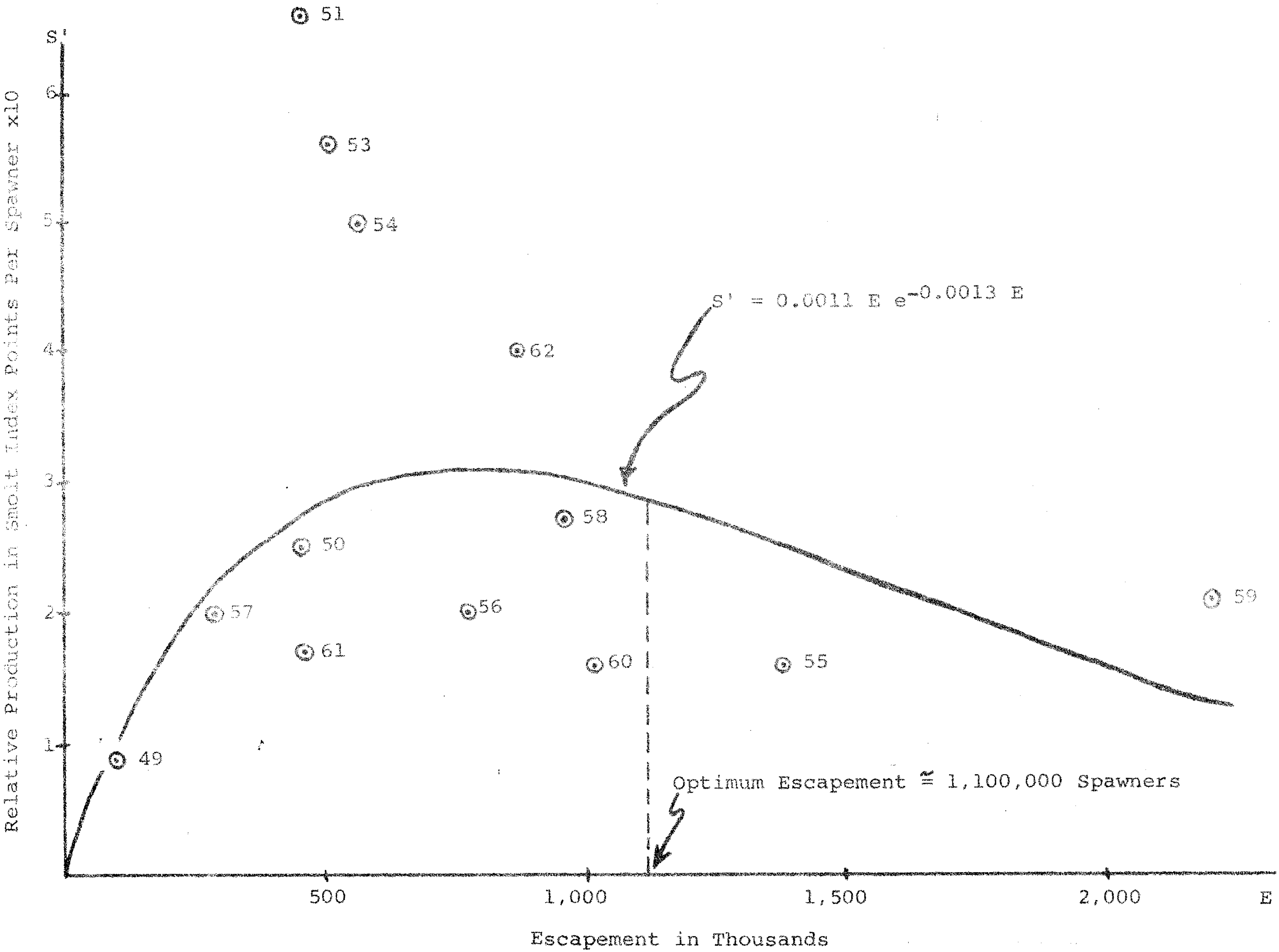


Figure 5. Wood River, Age I Smolt Length Versus Number of Smolt in Outmigration.

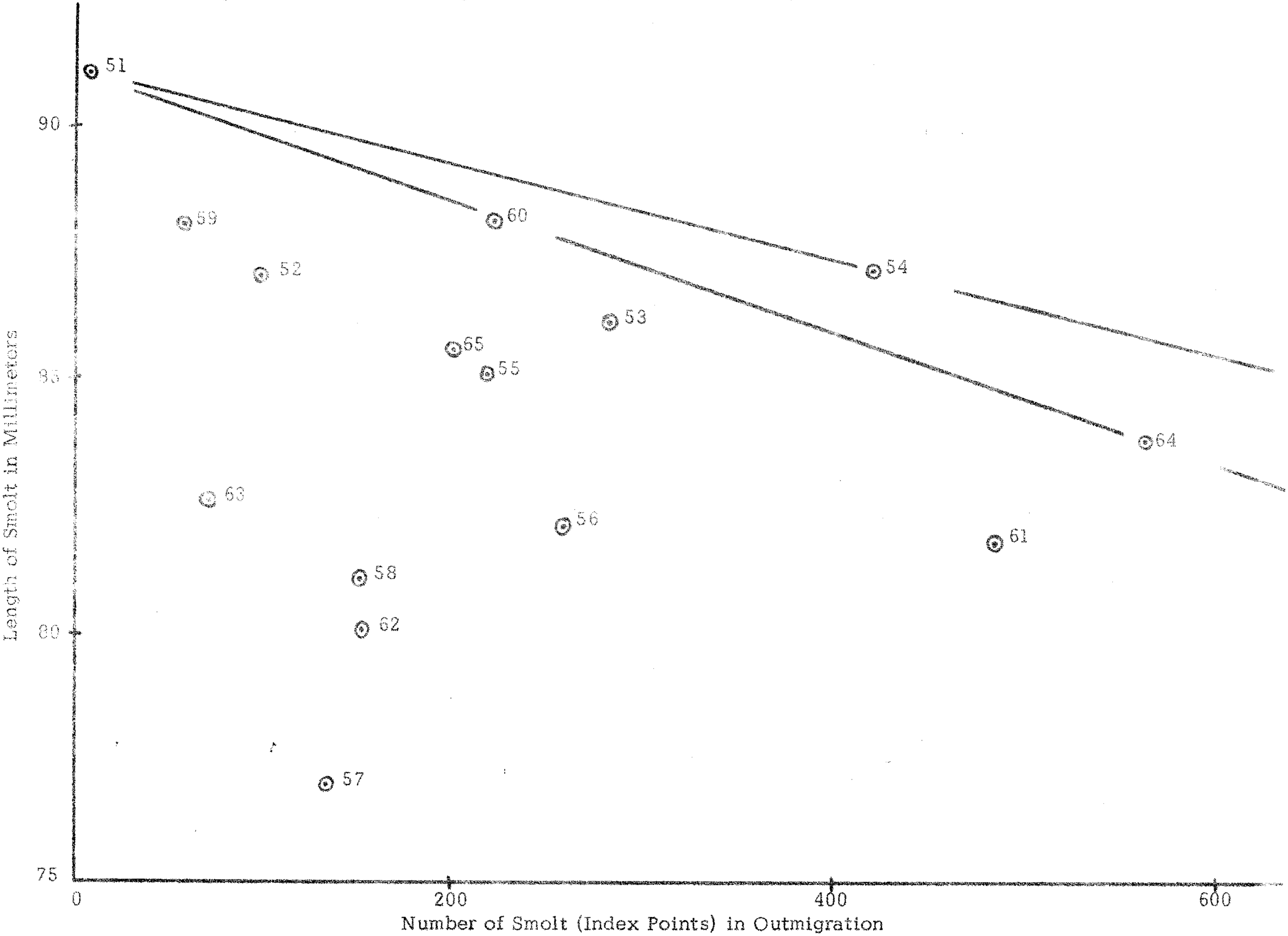
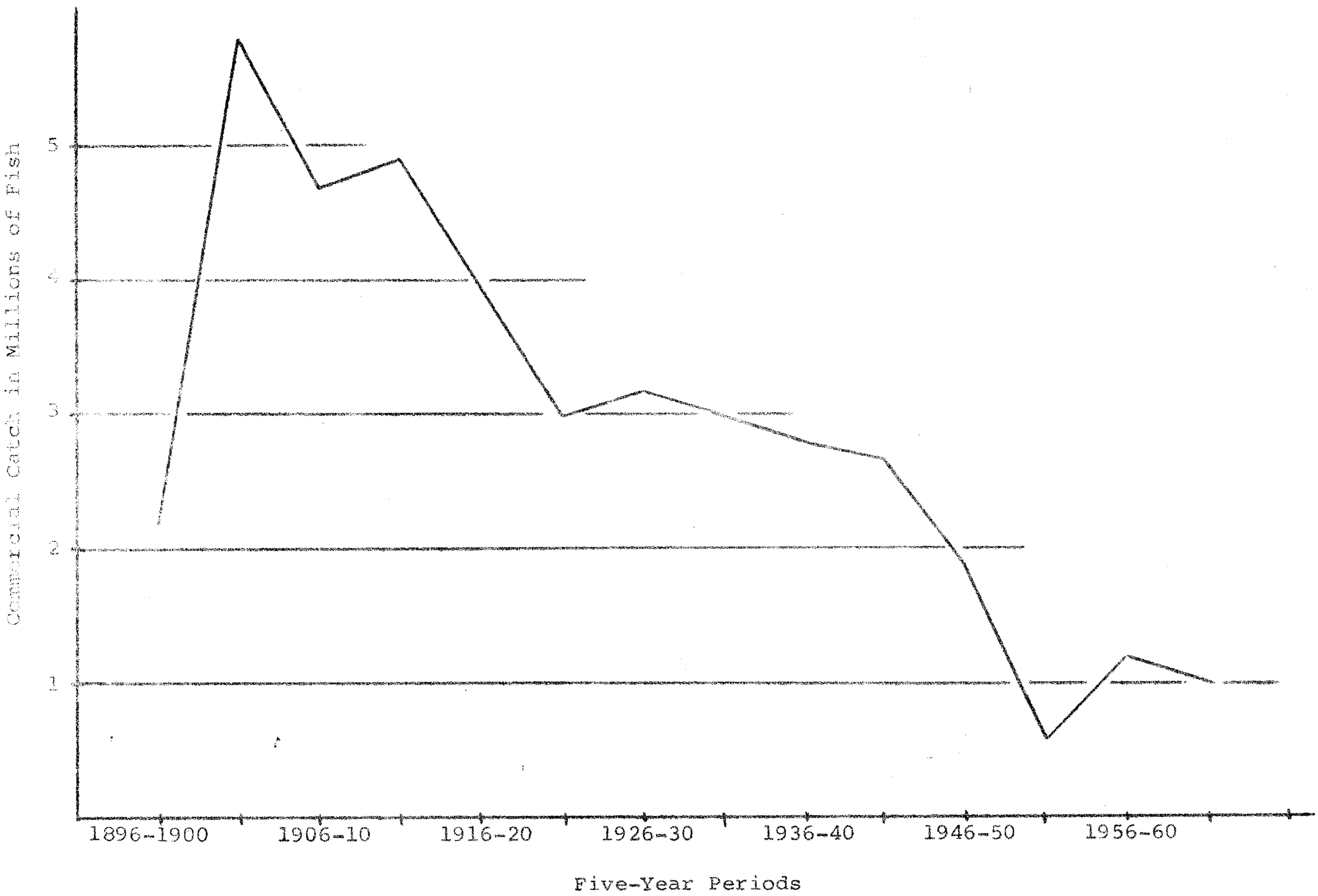


Figure 6. AVERAGE YEARLY COMMERCIAL CATCH OF RED SALMON FOR FIVE-YEAR PERIODS
NUSHAGAK DISTRICT, 1896-1965



IGUSHIK RIVER

1966 Prediction: 553,000

1966 Escapement Goal: 200,000

1966 Escapement Range: 150,000-300,000

Although no smolt data exists for the Igushik system, escapement-return data exists for the brood years 1947-60 (Ossiander, 1966). The years 1947-51 were omitted from these analysis since the high seas commercial catch data was not available for the years in which these runs returned. The brood year 1960 was included since only a small additional return of 6-ocean fish in 1966 is expected and this will not significantly change the return from 1960. The escapement, return and relative production data is given in Table 4.

Analysis yields a coefficient of determination $r^2 = 0.699$, indicating that 69.9% of the sum of squared deviation of ln R/E^2 is explained by the regression. Figures 7 and 8 show the return and relative production respectively plotted against the escapement. The curves fitted to the data are also shown.

The curve

$$R = 0.0484\ E^2\ e^{-0.0060\ E} \qquad (5)$$

fitted to the escapement-return data indicates an optimum escapement of approximately 290,000 spawners. Escapements to the Igushik system have averaged 223,856 sockeye for the years 1951-65. During this period, escapements were substantially larger than the indicated optimum escapements only four times.

On the basis of the production curve, the indicated optimum escapement would result in an average return of approximately 700,000 sockeye and, hence, an annual commercial yield of approximately 400,000 salmon.

In view of the 1966 predicted return of 553,000 sockeye to the Igushik system, the escapement goal of 200,000 represents an allowable harvest of 63.8%.

The 1966 escapement goal was set somewhat under the indicated optimum escapement for two reasons. First, in view of recent returns to this system, the prediction of 553,000 may be high. Secondly, the high percentage (74.9%) of 3-ocean fish may result in a large proportion of these fish being harvested on the high seas. If the return is as large as predicted, an attempt will be made to obtain escapement in the range of the indicated optimum escapement.

Table 3. Igushik River Red Salmon Escapement - Return Data[1] 1952-60
Number of Fish in Thousands

Brood Year	Escapement	Return	Relative Production
1952	150	535	3.6
1953	100	420	4.2
1954	80	640	8.0
1955	500	1,810	3.6
1956	400	789	2.0
1957	130	82	0.6
1958	107	140	1.3
1959	644	410	0.6
1960[2]	495	476	1.0

1/ Data Source: Ossiander, 1966.

2/ Does not include the 6-year fish which will return in 1966.

Figure 7. IGUSHIK RIVER RED SALMON ESCAPEMENT - RETURN DATA, 1952-60

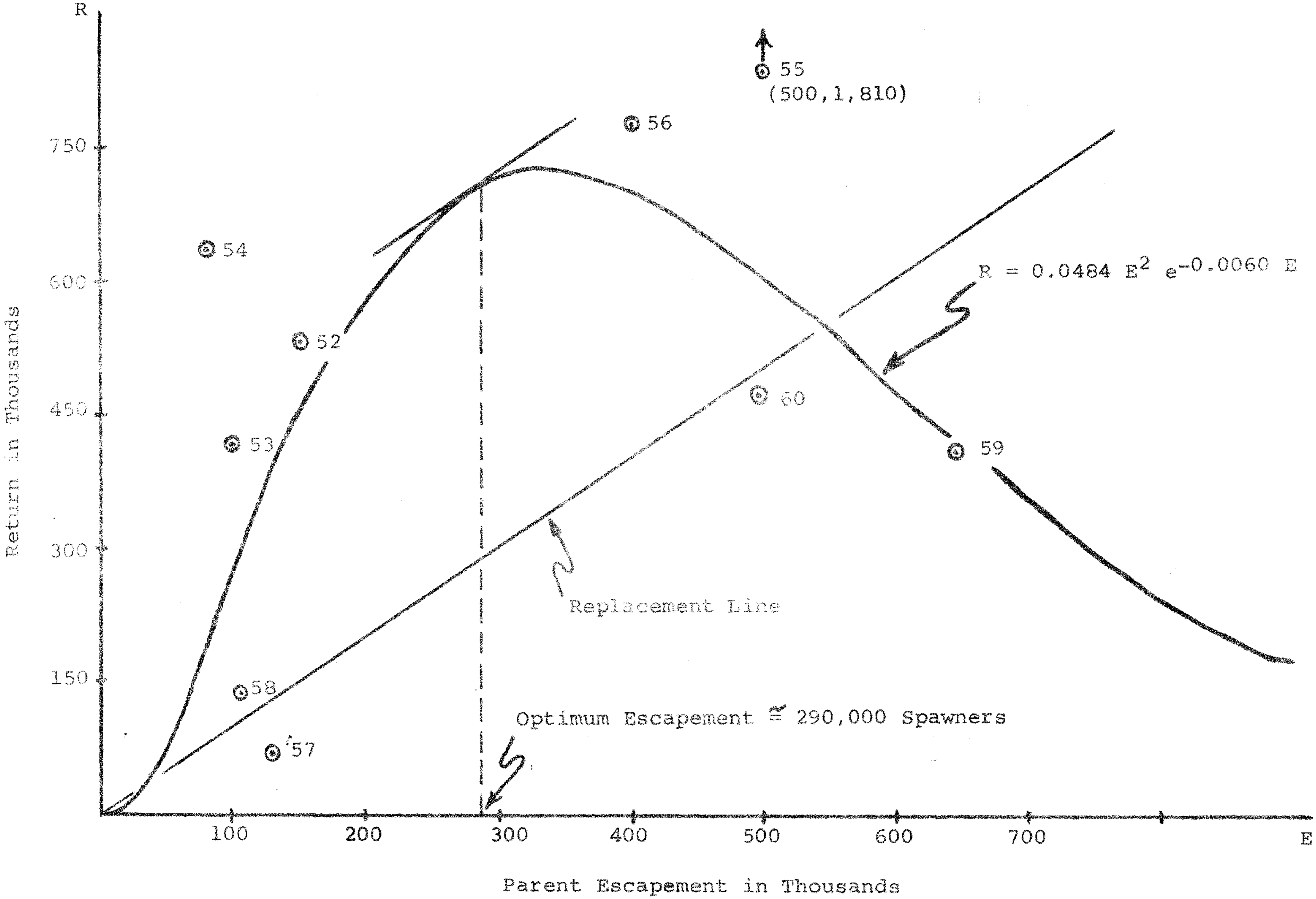
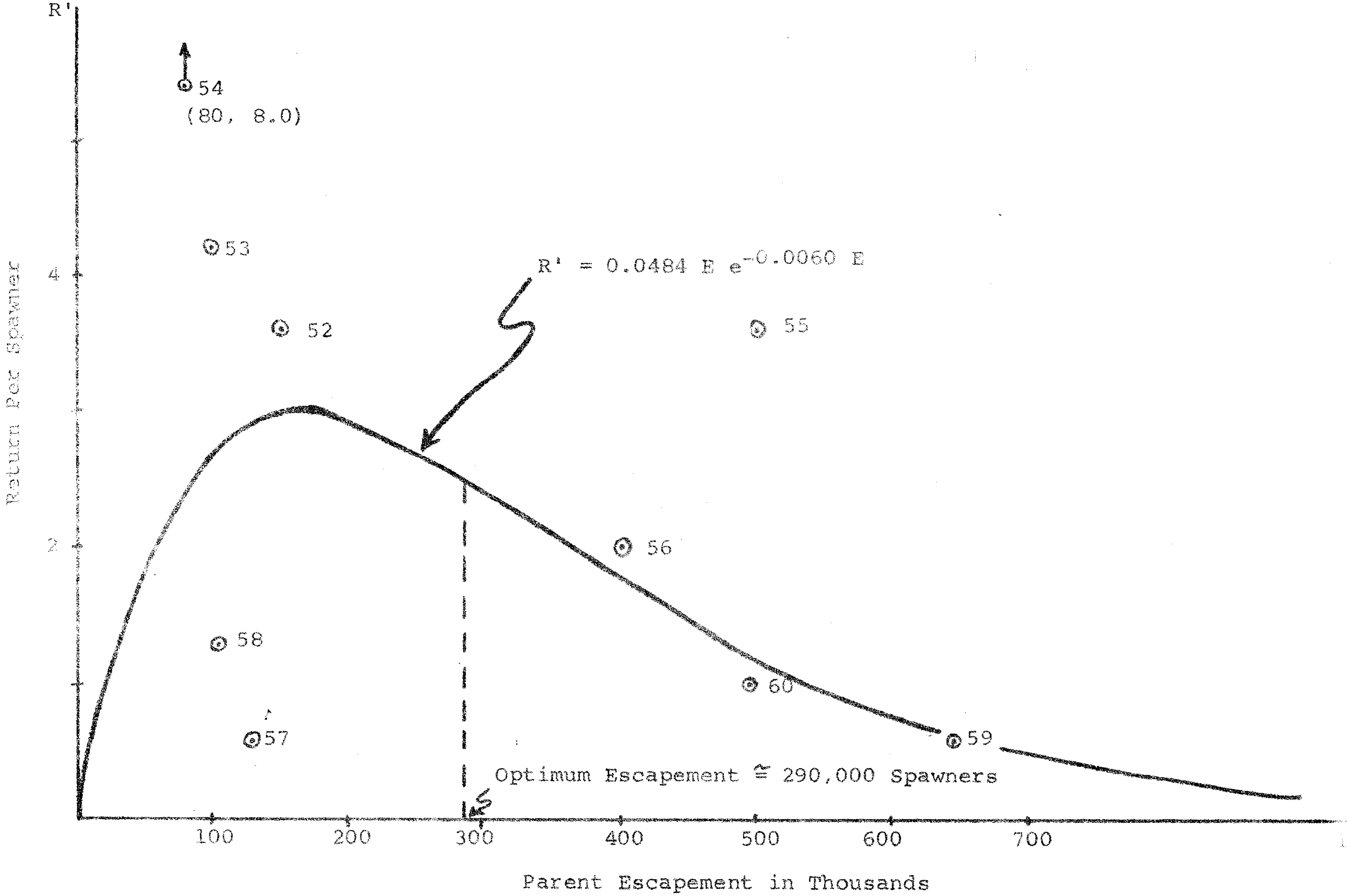


Figure 8. IGUSHIK RIVER RED SALMON ESCAPEMENT - RELATIVE PRODUCTION RELATIONSHIP, 1952-60



NUYAKUK RIVER (Tikchik Lakes System)

1966 Prediction: 241,000

1966 Escapement Goal: 150,000

1966 Escapement Range: 100,000-200,000

Escapement-return data is available (Ossiander, 1966) for the Nuyakuk system for the years 1946-1960. Data for the brood years 1946-51 were omitted from this analysis since the high seas commercial catch was not available for the returns from these years. The brood year 1960 was used since the return from that year is complete except for a very small number of 6-year fish which will return in 1966. The parent escapement, return and relative production for the brood years 1952-60 is given in Table 5.

Analysis yields a coefficient of determination $r^2 = 0.422$ indicating that 42.2% of the sum of squares of deviations of $\ln R/E^2$ is explained by the regression. The following production curve was obtained:

$$R = 0.1628\ E^2\ e^{-0.0141\ E}\ . \qquad (6)$$

Figures 9 and 10 show the return and relative production respectively plotted against the escapement and the curves fitted to these data. The escapement-return curve (Eq. 6) indicates an optimum escapement of approximately 125,000.

It should be noted that the production curve given by Eq. (6) does not closely describe the production of the three brood years with the largest escapements. A second curve (the dashed line curve) was fitted by eye to the data and it appears that this sketched curve provides some improvrment over the curve given by Eq. (6). Although the freehand curve indicates a slightly higher level of production, both curves indicate approximately the same level of optimum escapement.

The indicated optimum escapement of approximately 125,000 sockeye should be viewed as a minimum desired escapement level since the data on which this analysis is based is from recent years with relatively low levels of production. Data from larger escapements (200,000 and above) may very well indicate that a higher level of escapement is required for optimum production.

On the basis of the 1966 prediction of 237,000 sockeye to the Tikchik Lakes system, the escapement goal of 150,000 fish represents a 36.7% allowable harvest. This relatively low harvest rate reflects an effort by the Alaska Department of Fish and Game to increase the levels of escapement to this system which historically appears to have produced at much higher levels than in recent years. During the period 1951-65, spawning densities in the Tikchik Lakes system averaged 332 spawners per square kilometer as compared to 1,915 spawners per square kilometer in the Wood River Lakes.

From 1952 to 1960, the six low years which averaged escapements of 38,000 spawners produced an average return of 149,000 sockeye. The three years of relatively high escapements (average of 177,000 spawners) resulted in average yearly returns of 569,000 sockeye. The lower level of escapement represents an allowable harvest of 111,000 (74%) while the higher level of escapement represents an allowable harvest of 392,000 (69%). The desirability of obtaining escapements in the range of 125,000-200,000 spawners is apparent.

The Tikchik Lakes system stocks are not harvested in a district separate from the Nushagak fishing district (cf. Appendix). This presents a management problem of obtaining differential harvest rates on mixed stocks. The Nushagak district must be managed primarily for the predominant Wood River stocks which comprises 73.9% of the total predicted return to the Nushagak system in 1966. The desired harvest rate for the Wood River run is 62.7% as compared to the 37.8% desired harvest rate on the Nuyakuk stocks. There is, however, some indication that the Nuyakuk stocks enter the Nushagak district slightly earlier than the Wood River stocks. Therefore, restriction of fishing time during the early part of the season may provide the additional protection required for the Nuyakuk stocks.

Table 5. Nuyakuk River Red Salmon Escapement - Return Data,[1/] 1952-60, Number of Fish in Thousands

Brood Year	Escapement	Return	Return Per Spawner
1952	38	236	6.2
1953	189	587	3.1
1954	29	80	2.8
1955	16	77	4.8
1956	30	388	12.9
1957	67	19	0.3
1958	196	469	2.4
1959	49	96	2.0
1960[2/]	146	650	4.5

1/ Data Source: Ossiander, 1966

2/ Return does not include 6-year fish which will return in 1966.

Figure 9. Nuyakuk River Red Salmon Escapement-Return Relationship, 1952-60.

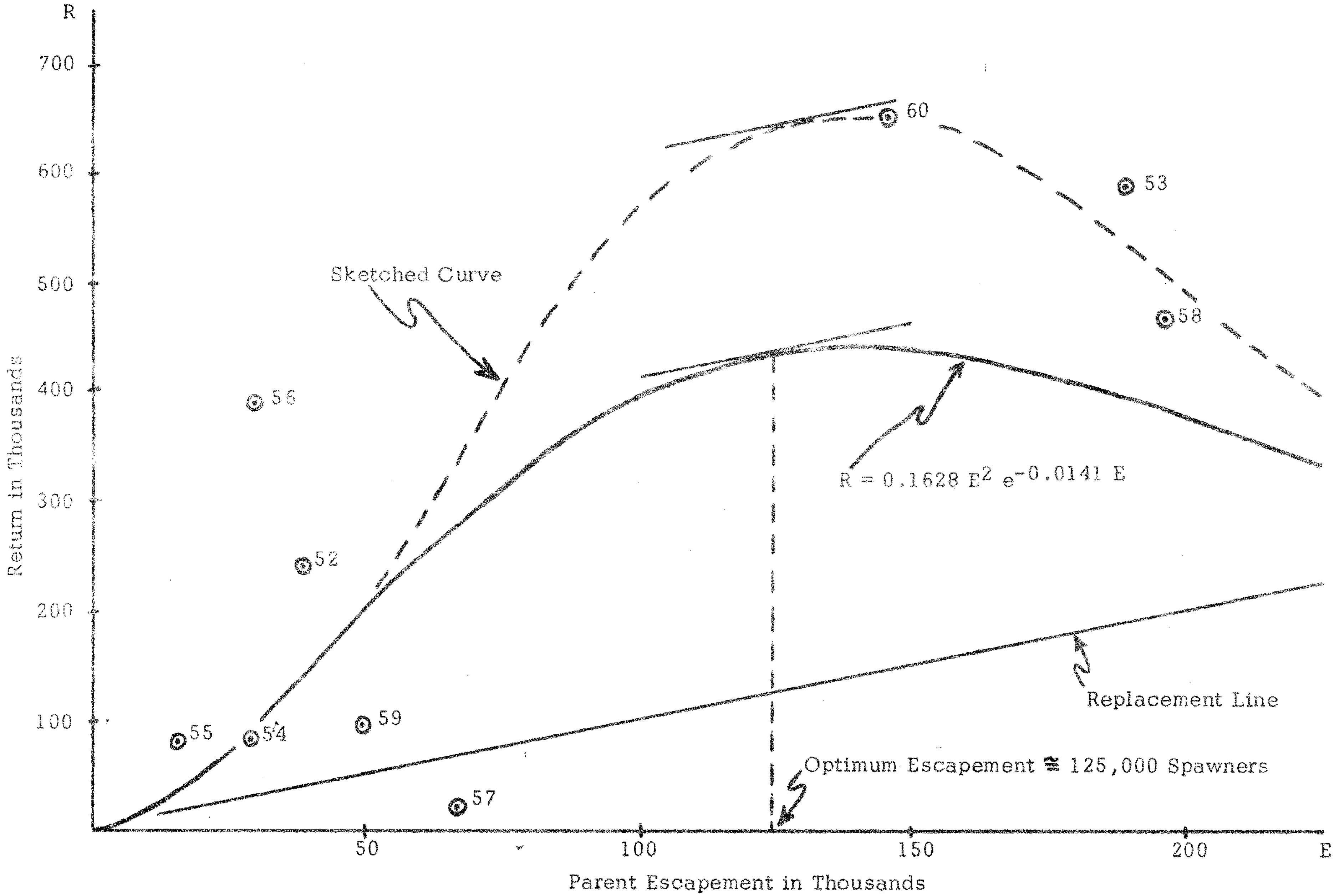
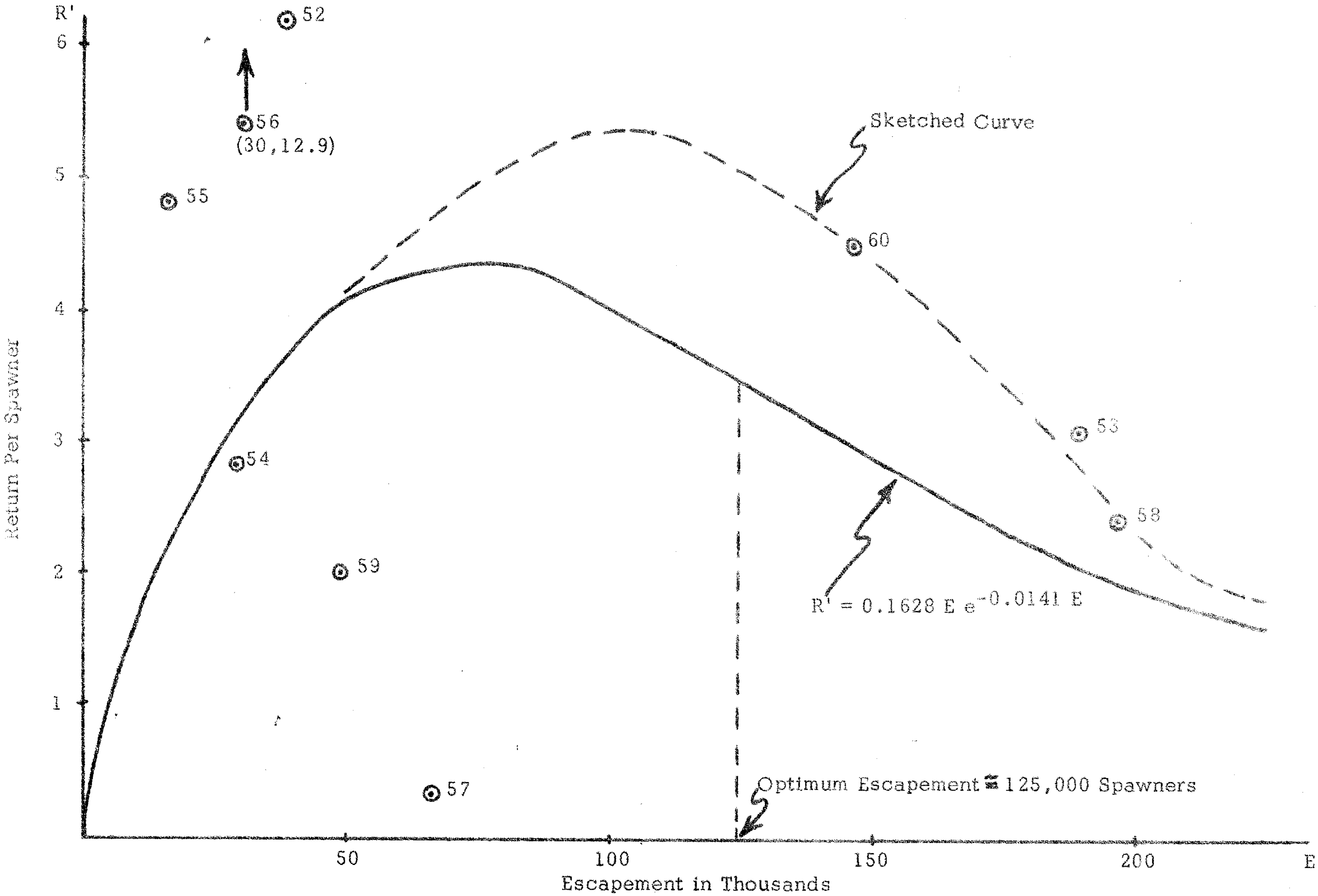


Figure 10. Nuyakuk River Red Salmon Escapement-Relative Production Relationship, 1952-60.



SNAKE, NUSHAGAK-MULCHATNA AND TOGIAK RIVERS

Only a very limited amount of data (Ossiander, 1966), both from the standpoint of series of escapement-return data and different levels of escapement, is available for the Snake, Nushagak-Mulchatna and Togiak systems. Furthermore, no smolt data is available for these stocks. Therefore, no attempt was made to determine production curves for these systems. Instead, average escapements and general levels of production are given on which escapement goals are based. The escapements to these systems for the period 1951-65 are given in Table 6.

Snake River

1966 Prediction: 11,000

1966 Escapement Goal: 11,000

Escapements to this system during the period 1951-65 have averaged 19,100 sockeye. During the same period, spawning densities in the Snake River system averaged 222 spawners per square kilometer as compared to 1,915 spawners per square kilometer for the Wood River system.

In an effort to increase the extremely low Snake River run, the Alaska Department of Fish and Game has restricted fishing in the Snake River section (Appendix) of the Nushagak district since 1961. The Snake River section will be closed again in 1966 to provide maximum protection for the estimated 11,000 returning sockeye. Unfortunately, the Snake River stocks are integrated with the Wood, Igushik and Nuyakuk stocks when they enter the Nushagak district, and therefore some Snake River fish are harvested with the other stocks. The desired escapement range for this system appears to be in the range of 40,000-80,000 spawners.

Nushagak and Mulchatna Rivers

1966 Prediction: 47,000

1966 Escapement Goal: 20,000

1966 Escapement Range: 10,000-30,000

These stocks are not managed as a separate unit as they enter the Nushagak fishing district integrated with the other Nushagak stocks. As mentioned earlier, the Nushagak district must be managed primarily for the predominant Wood River run. Therefore, if the 1966 runs return as predicted, approximately 29,000 sockeye will be harvested from the Nushagak-Mulchatna stocks while the allowable harvest (62.7%) for the Wood River run is being obtained. This leaves approximately 18,000 sockeye for escapement into the Nushagak-Mulchatna system.

Togiak River

1966 Prediction: 313,000

1966 Escapement Goal: 120,000

1966 Escapement Range: 100,000-180,000

The Togiak and associated commercial fishing districts are shown in the Appendix.

The Togiak fishery is a relatively young fishery as commercial fishing was not begun in this district until 1954. Although escapement estimates (aerial survey prior to 1960) are available since 1951, age composition data for the early years is limited, and hence only a limited amount of escapement-return data exists.

For the years 1957-58, escapements averaging 48,500 spawners produced returns averaging 197,000 sockeye. During 1959-60 escapements averaging 171,000 spawners produced an average return of 334,000 sockeye. This reflects relative production levels for the two periods of 4.1 and 2.0 returning adults per spawner respectively. Although a better relative production is indicated by the lower escapement level, assuming that the population would attain stability at these levels, the higher escapement level would result in a 10.1% increase in commercial catch. Escapements to this system have averaged 100,581 spawners for the period 1951-65. On the basis of this very meager data, a desired escapement range of 100,000 -180,000 sockeye has been set.

In view of the 1966 forecasted return of 313,000 sockeye, the 1966 escapement goal of 120,000 represents a 61.7% allowable harvest.

Togiak Tributaries

1966 Prediction: 30,000

1966 Escapement Goal: 15,000

1966 Escapement Range: 10,000-20,000

The Togiak River and Togiak tributaries stocks are managed as a unit, however, because of the large predominance of the Togiak River stocks, the fish bound for the tributaries are only harvested incidentally to the Togiak River fish. Therefore, with the anticipated harvest rate of 61.7% for the Togiak River run, approximately half or 15,000 Togiak tributary fish will be harvested.

Kulukak System

1966 Prediction: 10,000

1966 Escapement Goal: 5,000

1966 Escapement Range: 5,000-10,000

Estimates of escapements to this system are available for the years 1961-65. These escapements have ranged from a low of 5,200 in 1961 to 16,300 sockeye in 1965. The large escapement in 1965 probably reflects the maximum number of spawners this system can adequately handle. The escapement to this system very closely approximates the total return as a result of a very limited commercial fishery operating on these stocks. The 1966 predicted return of 10,000 sockeye and the escapement goal of 5,000 indicates a 50% allowable harvest.

Table 6. Snake, Nushagak-Mulchatna and Togiak River Red Salmon Escapements[1], 1951-65 (Number of Fish in Thousands)

Year	Snake	Nushagak-Mulchatna	Togiak
1951	3.0	2/	51.0
1952	4.0	15.0	102.0
1953	4.0	20.0	102.0
1954	4.0	8.0	57.0
1955	30.0	5.0	104.0
1956	4.0	5.0	225.0
1957	3.0	10.0	25.0
1958	9.0	5.0	72.0
1959	140.0	2/	178.7
1960	16.6	2/	162.8
1961	4.9	20.0	95.5
1962	1.8	8.5	47.4
1963	38.0	45.7	102.4
1964	12.4	10.8	95.6
1965	12.0	50.4	88.4
Averages	19.1	17.0	100.6

1/ Data Sources: a) Alaska Department of Fish and Game, 1965

b) Pennoyer and Seibel (Ed.), 1966

2/ Data not available.

KVICHAK RIVER

1966 Prediction: 21,638,000

1966 Escapement Goal: 6,000,000

1966 Escapement Range: 5,000,000-7,000,000

Introduction

The escapement goal of 6,000,000 spawners for the Kvichak River in 1966 reflects the current thinking of Alaska Department of Fish and Game management and research personnel as to the steps necessary to rebuild the Kvichak cycle to its pre-1941 magnitude. The 1965 run to the Kvichak was the largest on record. However, 1965 was the dominant cycle year on the Kvichak and does not necessarily indicate that the whole cycle will be exceptional. Past catch records indicate that early runs were generally good for three of five years, and poor for only one. This is a healthy status for the run both economically and biologically. The trend since 1940 has been one very good year followed by three or four poor ones. Such a fluctuation in run size is an extreme hardship on the industry and hinders the managing agency in securing adequate escapements from inadequate runs.

Figures 11 and Tables 7-8 provide background data on the Kvichak River such as catches, escapements, smolt production and returns. Unfortunately, detailed records on age composition are available only since 1957. Accurate escapement data and smolt index data is available since 1955. For this reason most of the statistical analysis of cycle mechanics, production and optimum escapement is confined to the years since 1952. This is unfortunate since the period 1952-63 is atypical in Kvichak history.

Catch History

The history of the Naknek-Kvichak fishery prior to 1955 can be expressed only in terms of annual commercial catches which are available for all years back to 1893. Discussion of Kvichak run fluctuations on the basis of these catches must be general at best because of certain inadequacies of the data, viz.

A. Influence of Naknek and Branch River sockeye runs on the Naknek-Kvichak district catch,

B. Extended fishing area for the Naknek-Kvichak district prior to 1953 (and consequent harvest of fish not bound for the Naknek-Kvichak system), and

C. Inadequacy of catch as an indicator of total return.

Even with these variables influencing the catches, they are the best information available for early years and probably reflect major abundance changes in the Kvichak runs. This is born out by the consistency of the catch patterns as illustrated in the following discussion.

The Naknek-Kvichak catch history can be generally divided into five periods.

1893-1910: The fishery was in the developmental stage. Many low catches with an annual average catch of only 4,237,000.

1911-1940: High, sustained production. Average annual catch of 10,326,000. Characterized generally by three very good years, one fair year and one poor year out of five. It is doubtful that the runs were being overharvested during most of this period since the same general level of production was maintained for 30 years. However, the last cycle of this period, 1936-1940, had the highest average annual catch in Kvichak history - 12,488,000, and the highest single catch - 20,967,834 in 1938. This production may have been at the expense of the escapement as indicated by the catch history of the following period.

1941-1951: As can be seen in Figure 11, prior to 1941 the end of each five year cycle of abundance was characterized by a year of very low catch (e.g. 1920, 1925, 1930) and the start of the next cycle was characterized by a catch of over 8,000,000 (e.g. 1921, 1926, 1931). Following this pattern, 1941 should have been a good year followed by one as good or better in 1942, another in 1943, a fair year in 1944 and a poor year in 1945. This did not happen. The catch and estimated escapement in 1941 were very poor. The poor catch in 1942 was due mainly to the small fishing effort during this war year and the run was stated to be good. The catch in 1943 was good and the escapement estimated as good. The 1944 run was fair and 1945 was very poor both in catch and escapement. Likewise, in the following cycle the run in 1946 was poor, 1947 very good, 1948 fair, 1949 poor, and 1950 poor.

During this period 1941-1951 the first year of the five year cycle virtually disappeared. The second year became dominant probably partially due to the greatly reduced fishing effort in 1942. The third year's run contributed to good but declining catches in 1943 and 1948.

Throughout the 1940's the catch for one or two years in each cycle remained in pre-1941 abundance. The overall average decline was due mainly to the drastic reduction in abundance of the remaining years in the cycle. In the period 1941-1951, the average annual catch declined to 6,484,095 red salmon.

1952-1963: Lowest production in the history of the fishery. Average annual catch of only 4,329,696. This period was characterized by a four year cycle of abundance with one good year, one mediocre year, and two poor years. However, even the peak years were not as good as in the 1940's. The cycle hit an all-time low catch from 1956-1959 with an average annual catch of only 3,295,000.

The changes from a five- to a four-year cycle of abundance is one of the important characteristics of the 1950's. Although it isn't clear whether the large 1952 run was a result of the 1947 (5-year cycle) brood year or the 1948 (4-year cycle) brood year, the 1952 run produced mainly 4-year fish.

Canadian studies (Ward, Larkin, 1964) and recent data on the Kvichak (Pennoyer, Seibel, 1965) have related length of stay in freshwater to growth and growth to abundance (competition for food between the same generation and following generations). It would appear that the decrease in abundance in the 1940's and early 1950's resulted in the majority of fry leaving fresh water after one winter's residence instead of two as they formerly had. Since most Kvichak fish spend only two winters in the ocean, this meant that they would return as four-year fish. Apparently the five year cycle does not necessarily result in abundant runs, rather abundance results in a five year cycle.

At this point it is appropriate to state that the Japanese high seas fishery for Bristol Bay red salmon began in 1952. Table 8 lists estimated Japanese catch of Bristol Bay red salmon by year and the estimated proportion of Naknek-Kvichak-Branch fish taken from 1956-1965.

From 1956-1965, the high seas fishery took an estimated 23.8 million Naknek-Kvichak sockeye. Although the addition of these fish to the inshore harvest would still leave the average annual catch well below the average catches in the 1940's, the same number of fish added to the escapements to these rivers might have substantially reversed the decline.

<u>1964-1965</u>: A dramatic change occurred in run size. The large escapement (14,630,000) in 1960 produced only 1,256,000 4_2 fish in 1964. However, in 1965 41,382,926 5_3 fish returned from the 1960 brood year. Most of the progeny of the 1960 run had held over for a second year in the lake to return as 5-year fish. The Kvichak reverted to a five-year cycle and in 1965 produced the largest recorded run and second largest catch in the Naknek-Kvichak district history.

The Kvichak had been building to this point since 1952. In 1952 an estimated escapement of 5,970,000 fish reached the spawning grounds. In 1956 this number increased to 9,443,000 and in 1960 to 14,630,000. The five year cycle was apparently initiated by the abundance of fry from 1960 causing an additional year holdover in the lake with the smolt leaving freshwater as 3-year fish. The 1960 escapement level, therefore, produced a single year in a five year cycle that has a catch equal to that of the 1930's. Large production as from the single 1960 brood year will not, however, produce the cyclic abundance which existed in the period 1911-40. The peak cycle years 1952 and 1956 were the only significant contributors to the total runs of the following cycle. Sockeye returning from the 1952 parent year provided 78% of the total 1956-59 return. Similarly, sockeye from the 1956 parent year provided 84% of the 1960-64 return.

Actually then, the huge 1965 run by itself does not imply a return to previous levels of abundance. It could be expected to produce a large run of 5_3 fish in 1970 and a good run of 6_3 fish in 1971, leaving 1972-1974 as poor years. The total "cycle harvest" would not reach former abundances and the economic burden of extremes from year to year would not be lessened. We are still apparently in the same cycle pattern of a single dominant year as in the 1940's and 1950's. All we have done is increase its size and return the cycle to its five year period.

Optimum Escapement

As mentioned before, the period 1911-40 was characterized by three good years, one fair year and one poor year out of each five year cycle. As one good brood year could only be expected to result in at most two years of good return, at least two of the five years must have had good escapements. Assuming that at least two good escapements of a five-year cycle are necessary to maintain peak abundance, the next question is how large should they be? For this we must largely confine the discussion to recent years (since 1952) for which detailed data on catch, escapement and smolt are available.

Peak (Dominant) year(s)

This term may not be applicable to pre-1941 cycles since, strictly speaking, there was no one peak year. However, the present data indicates that one year (the first in the cycle) will get the largest escapement. This is true for this cycle since we already have a 24,325,000 escapement in 1965 in the Kvichak.

Production from Kvichak spawning populations may be expressed in terms of smolts or adult salmon. In recent years, smolt production has been used primarily to measure the success of different levels of spawning as final returns were available for only one peak year (1956) for which an accurate estimate of escapement was available. However, the relatively large discrepancy between forecasted returns (based on smolt-return relationships) and actual returns in recent years has raised some question as to the reliability of smolt indices as indicators of the true smolt outmigration for the Kvichak River.

Equation (2) was fitted to both the escapement-smolts produced data and the escapement-return data. To facilitate analysis, the smaller escapements (less than one million) were grouped and averages taken. The following two equations were obtained:

$$S = 3.06 \times 10^{-4} E^2 e^{-1.74 \times 10^{-4} E} \qquad (7)$$

and

$$R = 18.92 \times 10^{-4} E^2 e^{-1.50 \times 10^{-4} E} \quad . \qquad (8)$$

Analysis yielded coefficients of determination of -0.757 and 0.586 for the variables $\ln S/E^2$ and E and $\ln R/E^2$ and E respectively. Curves for Equation (7) and (8) are sketched in Figures 12 and 13 respectively.

Equation (7), based on smolt data, indicates optimum escapement in the range of 9-12 million. A freehand curve sketched to fit the brood years 1956 and 1960 better than Eq. (7), indicates optimum escapement in the same range, but indicates slightly higher production from these escapements.

Unfortunately, smolt production is available for only two peak years (1956, 1960) and the production from the eight subdominant smaller years adds very little to determining the shape of the curve. This and the questionable reliability of the smolt index as an indicator of total outmigration indicate that optimum production in terms of smolts should be viewed with caution.

Equation (8), based on escapement-return data, indicates that optimum production is obtained from escapements of 11-12 million spawners. One point in particular should be noticed in Figure (13), viz. that the points representing the years 1952, 1956 and 1960 very nearly form a straight line. The implication is that escapements in this range produce equally well, with no apparent decrease in production efficiency. In conjunction with this, two other factors should be considered.

First, although the large peak years do not show any apparent decrease in production as a result of large densities of spawners and consequent large densities of fry in the lake, the year(s) immediately following the peak year may be affected.

Secondly, the actual return of 6_3 sockeye to the Kvichak in 1966 may change the picture given by Figure 13. If the return is as predicted (or larger), the picture will remain basically the same. If, however, the 6_3 return is substantially smaller than predicted, the 14.6 million escapement in 1960 could represent escapement somewhat in excess of optimum escapement.

If the horizontal and vertical scales were identical in Figure 13, a very rapid increase from zero production to maximum production over a small range (0-11 million) of escapements would be apparent. Thus, small decreases in escapement levels (less than the optimum escapement) result in rather drastic decreases in production. E.g. a decrease in escapement from 10 to 7 million spawners results in a decrease of 42 to 32 million return, or a decrease in commercial yield of 7 million fish. Because of the variability inherent in both production and management, and because of the very significant decrease in production with decreases in escapement below 12 million spawners, a safety factor (dependent on variability of return and success in management) should be included in the escapement goal. Ricker (1963) discusses the serious consequences of overharvesting a population for which the maximum rate of exploitation is relatively large (75% or more) as is the case with the population described above.

At this point, we should refer to the past catch records, in particular those for the period 1911-40. Average annual catches are given below for several periods within the period 1911-1940:

Period	Average Annual Catch (N/K District)
1911-16	10.4 million
1911-35	9.9
1936-40	12.5

As stated previously, the last cycle (1936-40) of the period 1911-40 produced the highest annual catch (for any given cycle). The 12.5 million average annual catch for the period 1936-40 represents 26.3% and 20.2% increases over the average annual catches for the periods 1911-35 and 1911-16 (second highest average annual catch) respectively.

Assuming a stable population producing at optimum rate (as described by the curve of Figure 12) an additional increase of 20% in commercial harvest (and the corresponding decrease in escapement) would reduce the total return from approximately 45 million to 25 million sockeye. In fact, a decrease in the 1941-45 cycle did occur, beginning a decline which has lasted until 1965.

A comparison (USFWS, 1964) of spawning densities for sockeye systems in southwestern Alaska states that the highest average spawning density observed for the period 1955-62 was 8,380 spawners per square kilometer of lake area for Karluk Lake. The 24.3 million spawners in Lake Illiamna in 1965 represents a spawning density of 7,364 (12% less) sockeye per square kilometer indicating that even this seemingly high number of spawners may not be excessive for the Kvichak system during a dominant year.

A final point might be made regarding the production curve of Figure 13. The three dominant years, 1952, 1956 and 1960, represent peak years of a four-year cycle with only one dominant year. Assuming that lacustrine intra- and inter-specific competition and predation are the cyclic mechanisms, a reduced rate of relative production for the two or three dominant years of a five-year cycle might be expected. This, however, does not necessarily imply a reduced total production for the cycle.

The discrepancy between the escapement-smolt and escapement-return curves may be attributed to the 1956 Age II smolt index being too high, the 1960 smolt index being too low, a differential marine survival rate between the two groups, or some combination of these factors. The second factor in particular is suspected since the forecasted return (based on smolt-return relationship) for 1965 was approximately 33,000,000 sockeye less than the actual return.

Assuming 1) the desirability of returning to the pre-41 pattern (and level) of abundance, and 2) that Age II smolt are a direct effect of high levels of production, then the production of Age II smolt (and hence a five-year cycle) can be used as an indicator of reaching those levels of escapement which were present in the pre-41 era. Available data (cf. Figure 14) indicates that 50% Age II smolt production occurs at approximately 10,000,000 spawners. If inter-generation competition exists and we increase following year's escapements, the percentage of Age II smolts produced may increase at a greater rate with escapement size than at present. This will also vary with environmental factors. At any rate, the minimum figure desired for the peak year escapement would be 10,000,000 spawners.

<u>Sub-dominant years</u>

To produce fish in significantly large numbers in any but the first two years of a five-year cycle, adequate escapements must be secured for more than one year in the cycle. The level of production possible from the sub-dominant years will depend on the present cycle mechanisms.

The Kvichak cycle mechanisms have not been completely determined, but available evidence suggests that although all generations cannot be increased to the same level of production, it should be possible to maintain peak production for two and possibly three years of the five-year cycle as was apparent during the period 1911-40.

As illustrated in Figure 14, the year following the peak year produced the highest percentages of Age II smolt in the cycle, indicating some effect by the large peak year escapements. The third and fourth years of the cycle with small escapements indicate variable percentage production of Age II smolt and apparently ecological and/or hereditary factors partially regulate freshwater age. However, this apparent effect of peak years on subsequent years should not be construed as necessarily producing significantly larger mortalities in the following brood year stocks. In Figure 15, relative production (return per spawner) is plotted against escapement. With the exception of 1955, all sub-dominant years reflect lower relative production than do the peak years. However, it should be noted that the sub-dominant year's escapements were all less than three million spawners, in fact, with the exception of 1957, the escapements were less than one million sockeye. The curve fitted to this data is based on the assumption that severe depensatory mortalities act on the smallest escapements. If the poor relative production of these small escapements were due to the large peak year's escapements, we would not expect the pattern of three consecutive years with high production which is reflected by the period 1911-40. As mentioned previously, however, the peak relative production for the pattern existing in the 1911-40 period may be less than relative production of the one peak year of a four-year cycle.

Although there is some indication that increasing the peak year plus two (the second year following the peak year) rather than the peak year plus one would be more productive (due to reduced competition with the peak year), at the present level of the run it is unlikely that a large escapement can be secured for the peak year plus two (1967), whereas a good run is expected in 1966 from which an adequate escapement could be obtained. A good escapement in 1966 may provide a good return in 1972 (peak year plus two) from which an adequate escapement can be obtained. It is important to initiate this trend by securing an adequate escapement in 1966.

In view of 1) the very rapid decrease in relative production for escapement less than 6 million and the good relative production for the range of 6-12 million spawners, 2) the relatively large total production for escapements in the range of 6-12 million, 3) the importance of obtaining a good escapement to build up the sub-dominant years and 4) the 1966 predicted return of 21,638,000 sockeye, a minimum 1966 escapement goal of 6,000,000 spawners has been set.

Although the forecasted return to the Kvichak River in 1966 is 21.6 million sockeye, as mentioned previously, the inshore return could be reduced substantially in view of the high seas fishery. Should the 1966 inshore return be stronger than anticipated, the escapement goal may be increased accordingly as escapements in the range of 6-12 million are desirable.

Summary and Conclusions

1. It is desirable to return to pre-1941 patterns of abundance in the Kvichak system. These were characterized by a five-year cycle with three or four years of high abundance. At least two good escapements during the five-year cycle are required to maintain this pattern.

2. Analysis of data for the period 1952-65 indicates that for dominant years, escapements near the twelve million level should be secured. Because of the drastic reduction in total returns for smaller escapements, safety factors should be included in the establishment of escapement goals. A return of 6_3 sockeye as predicted in 1966 might result in an increase in the indicated optimum escapement for the peak year.

3. Data for the period 1911-40 does not indicate an extreme effect of a large peak year on the following years. Poor returns from small escapements of sub-dominant years for the period 1952-60 appear to be a result of depensatory mortalities other than competition with the peak year. A minimum escapement of 6 million spawners is recommended for the 1966 season.

Table 7. Kvichak River Red Salmon Production Data 1/, 1952-62.
Number of Fish in Thousands

Brood Year	Escapement	Smolts Produced 2/	Smolts Per Spawner	Adult Return 3/	Return Per Spawner
1952	5,970	4/	4/	23,041	3.86
1953	321	66	0.21	600	1.87
1954	241	39	0.16	758	3.15
1955	250	89	0.36	1,553	6.21
1956	9,443	6,045	0.64	38,324	4.06
1957	2,964	639	0.22	3,950	1.33
1958	535	72	0.13	285	0.53
1959	680	98	0.14	568	0.84
1960	14,630	5,247	0.36	58,875 5/	4.02
1961	3,706	1,717	0.46	4/	4/
1962	2,581	2,206	0.85	4/	4/

1/ Data Sources: a) Pennoyer, 1966
b) Ossiander, 1966

2/ 24-hour index catch of smolts. This is number of smolts, not index points.

3/ Includes high seas commercial catch.

4/ Data not available.

5/ Includes predicted 1966 return of 6_3 fish.

Table 8. Naknek-Kvichak District Red Salmon Returns and Japanese High Seas Catches 1/, 1956-65 (No. of Fish in Thousands)

Year of Return	Japanese Catch of Bristol Bay Reds 2/	Japanese Catch of Naknek-Kvichak Reds	Naknek-Kvichak Inshore Run 3/	Naknek-Kvichak Total Run 3/	Percent Naknek-Kvichak Run Taken by Japanese
1956	2,812	1,753	19,080	20,833	8.4
1957	9,735	6,927	8,371	15,298	45.3
1958	1,356	430	1,783	2,213	19.4
1959	1,221	417	5,397	5,814	7.2
1960	5,192	2,695	26,546	29,241	9.2
1961	7,388	4,563	12,282	16,845	27.1
1962	1,377	773	5,653	6,426	12.0
1963	1,286	425	2,395	2,820	15.1
1964	1,444	526	4,650	5,176	10.2
1965	8,005	5,260	44,335	49,595	10.6

1/ Data Source: Ossiander, 1966

2/ Includes immature salmon taken one year prior to the year which they would have normally returned to Bristol Bay.

3/ Includes 2- and 3-ocean fish only.

Figure 11. NAKNEK-KVICHAK DISTRICT RED SALMON CATCH, 1893-65
(Data From INPFC Document 444, 1960 and Alaska Department of Fish and Game Records)

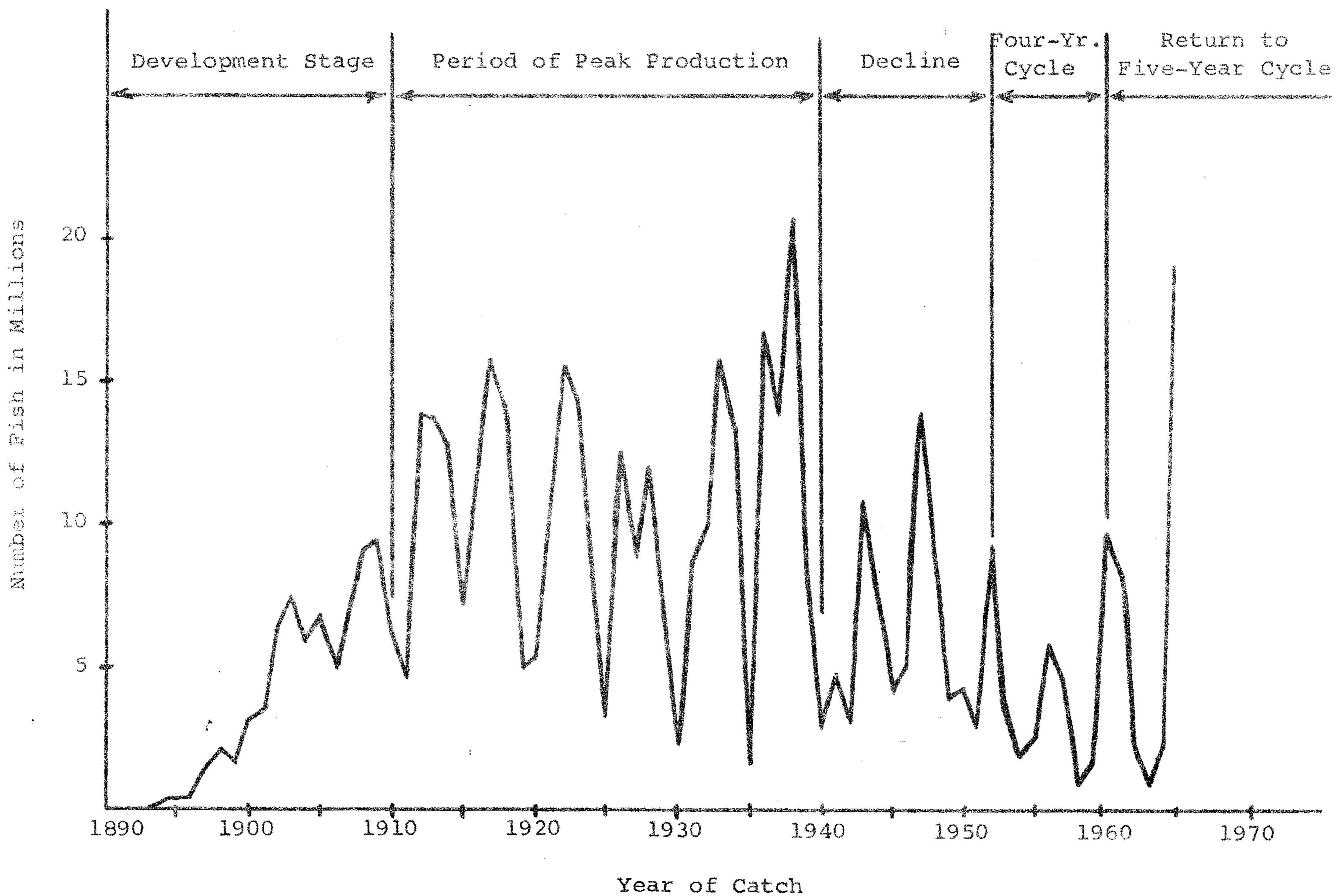


Figure 12. Kvichak River Red Salmon Escapement - Smolt Production Relationship, 1953-62.

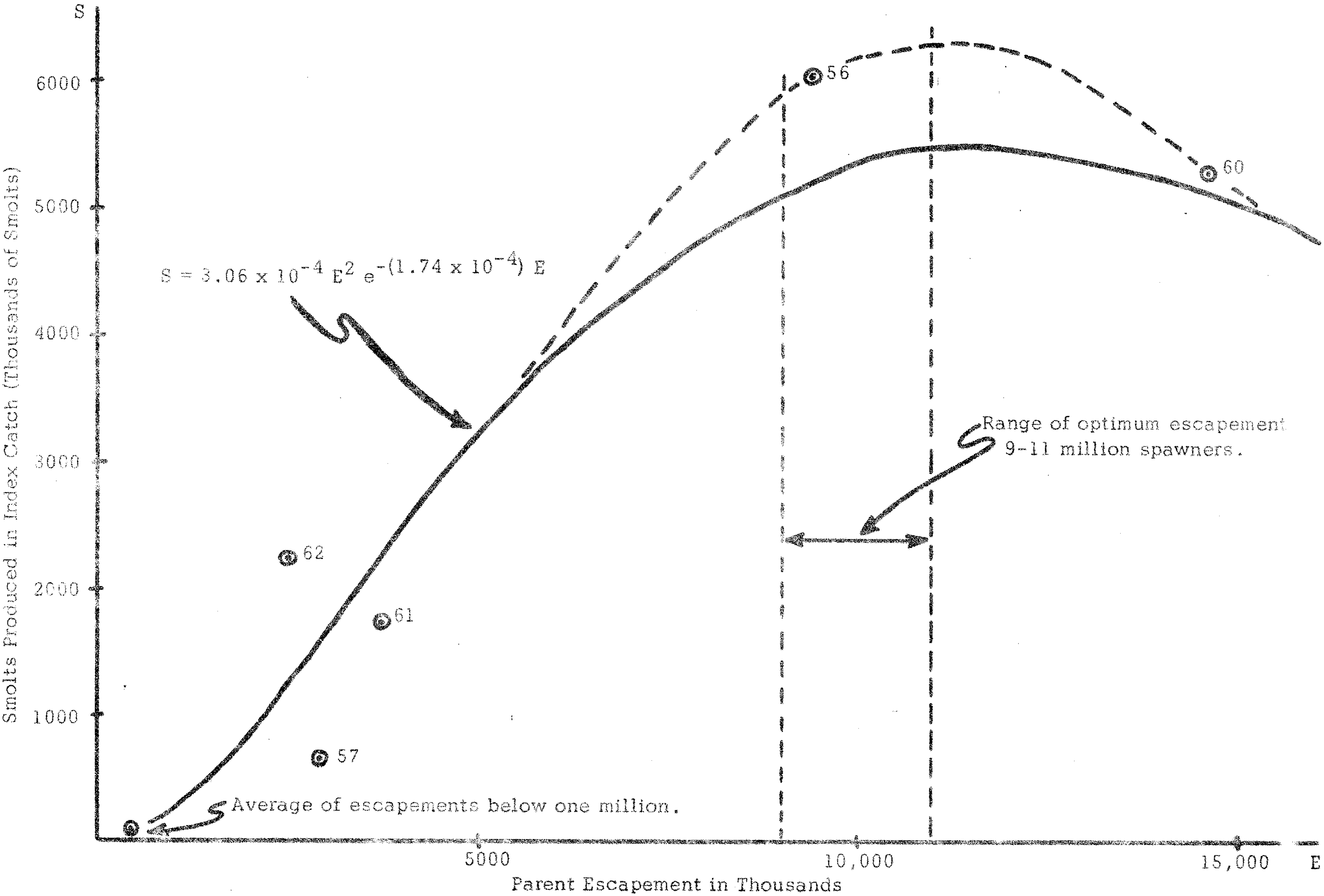


Figure 1 . Kvichak River Red Salmon Escapement-Return Relationship, 1952-60.

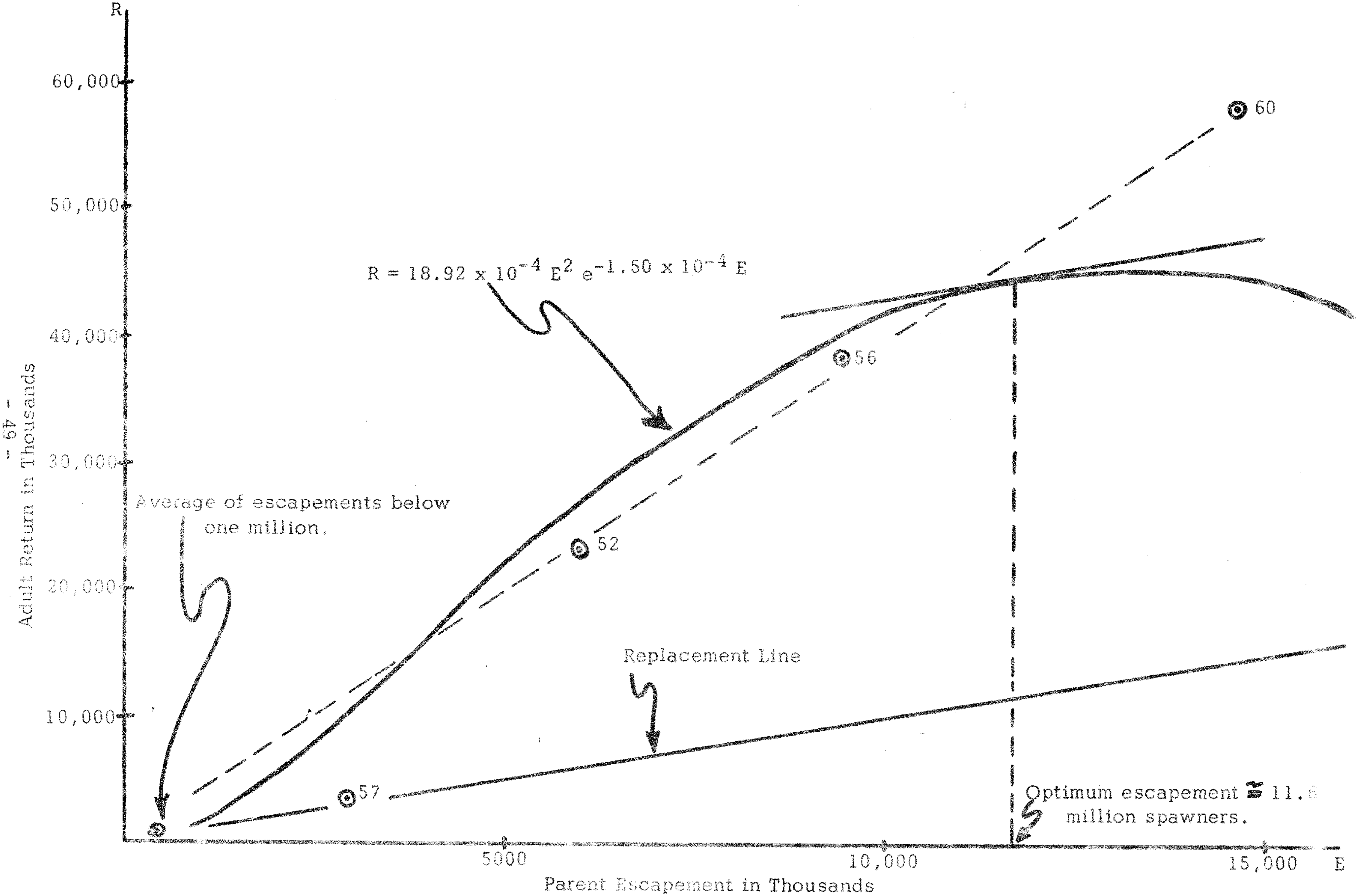


Figure 14. KVICHAK RIVER RED SALMON PER CENT PRODUCTION OF AGE II SMOLT, 1952-62

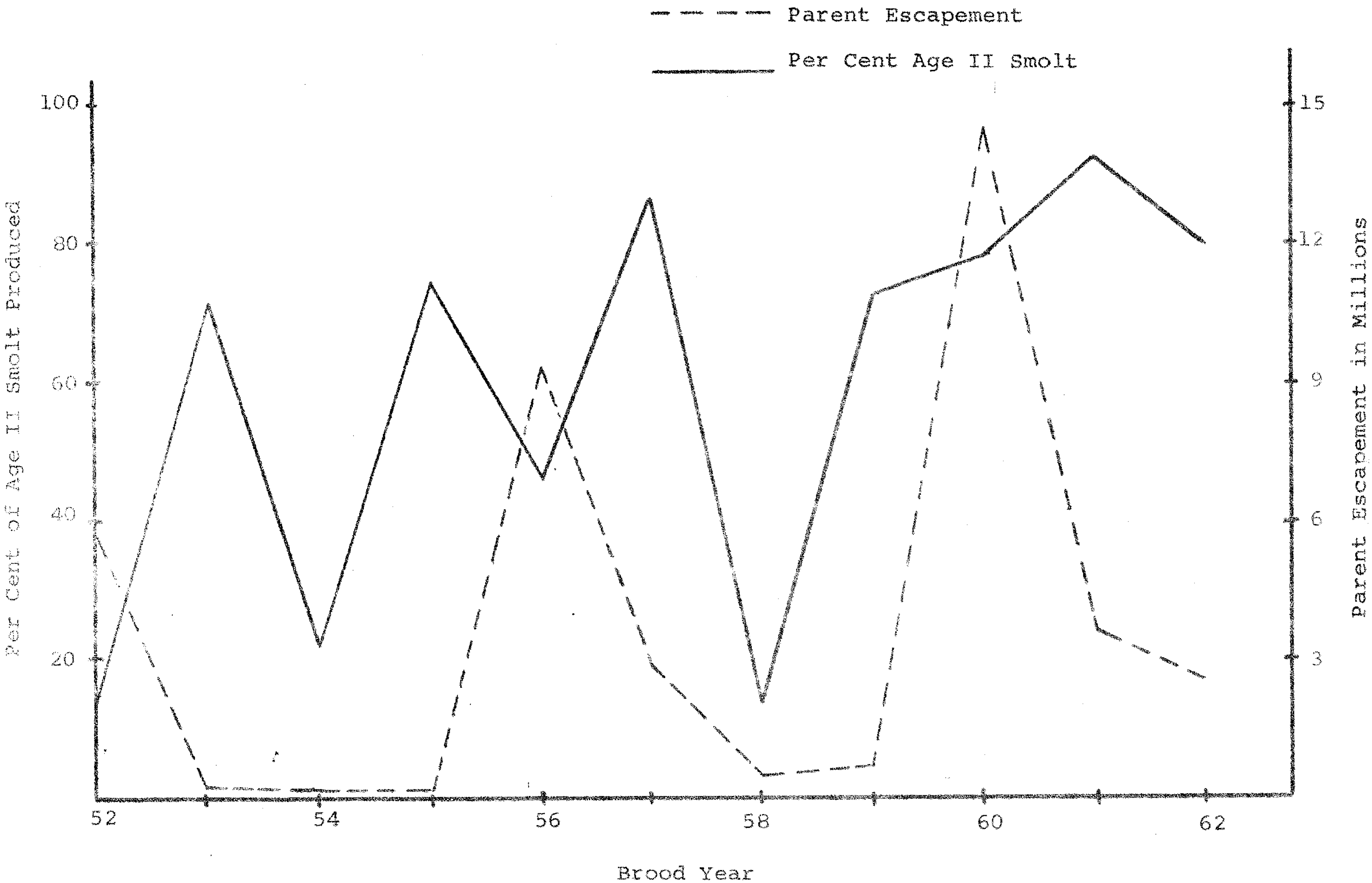
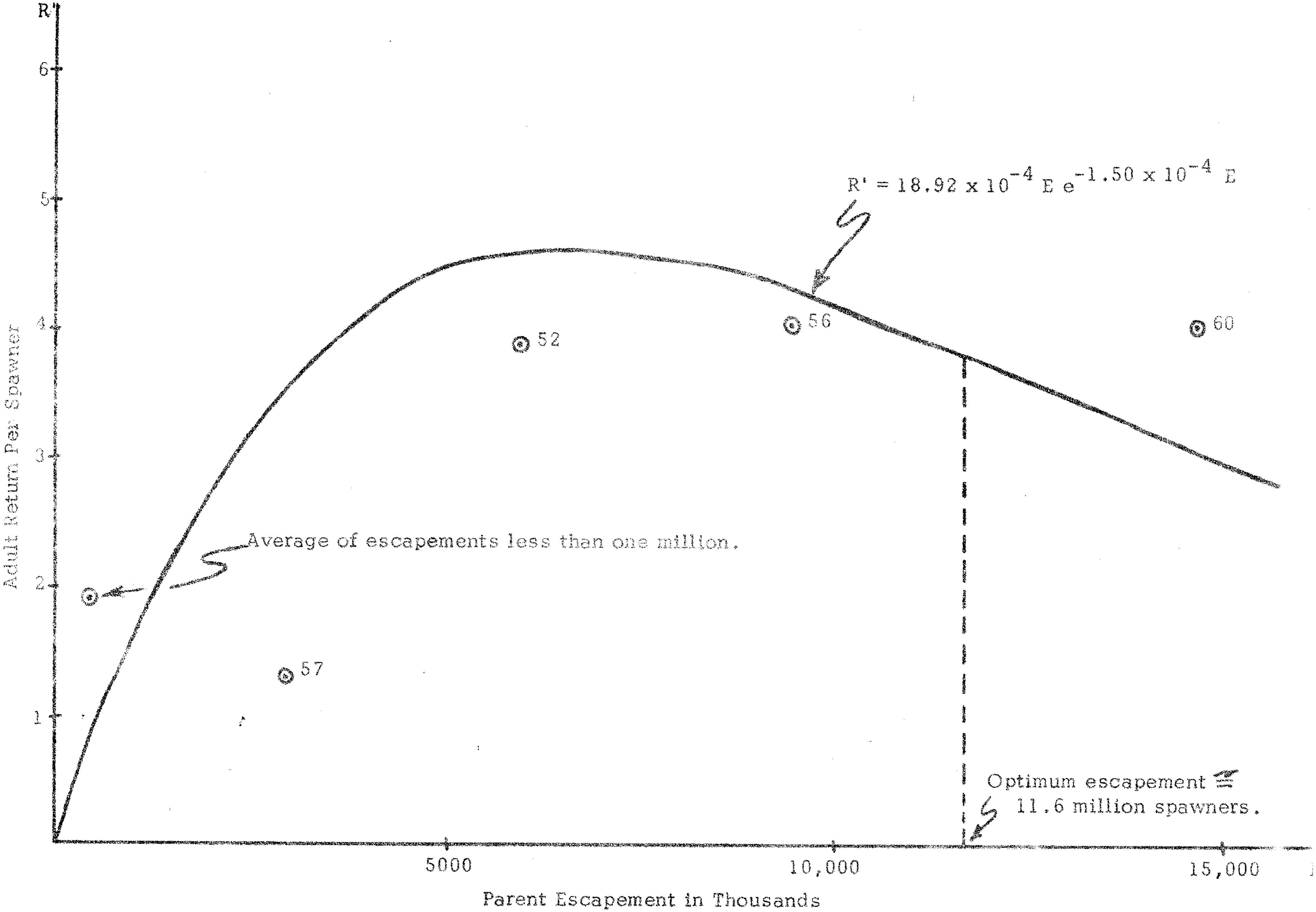


Figure 15. Kvichak River Red Salmon Escapement-Relative Production Relationship, 1952-60.



NAKNEK RIVER

1966 Prediction: 1,867,000

1966 Escapement Goal: 800,000

1966 Escapement Range: 700,000-1,000,000

Smolt studies conducted on the Naknek system have provided estimates of yearly smolt outmigration since 1956. Table 9 gives the parent escapement, smolts produced and relative production for the brood years 1954-62.

Analysis yields a coefficient of determination $r^2 = 0.855$ indicating the 85.5% of the sum of squares of the deviation of $\ln S/E^2$ are explained by the regression. The following equation was obtained:

$$S = 0.0759\ E^2\ e^{-0.0016\ E} \qquad (9)$$

It might be noted that use of Eq. (1) resulted in only a slight difference regarding the level of optimum escapement for this system.

Figures 16 and 17 show production and relative production respectively plotted against escapement and the curves fitted to the data. An optimum escapement of approximately one million spawners is indicated if a marine survival (cf. Table 10) of 17.9% is used.

The fact that the marine survival associated with the 1957 outmigration was greater than 100% (implying that more salmon returned from the ocean than migrated from the Naknek system) indicates that either a) the smolt outmigration in 1957 (smolt from the brood years 1954 and 1955) was under-estimated, or b) the returns to the Naknek system in 1959 and 1960 were over-estimated. A combination of these factors could also have caused these contradictory results. As can be seen from Figure 16, the two brood years 1954 and 1955 fall below the production curve as well as below the parent years with similar escapements. Thus, it appears that (a) above was at least partially the cause of the inconsistency reflected in the marine survival of the 1957 outmigration. Adjusting the production from the years 1954 and 1955 in such a manner that they would fall in line with other years of similar escapement would not have a large effect on the production curve but would tend to move the point of optimum escapement slightly to the right.

The indicated optimum escapement of approximately one million spawners compares favorably to the estimated (USFWS, 1964) spawning capacity of 1,340,000 adults (assuming equal sex ratio) for the Naknek system. Since 1955, escapements to this system have averaged 915,541 sockeye with three of the eleven years having escapements in excess of one million fish.

In view of the predicted return in 1966 of 1,867,000 sockeye to the Naknek system, the escapement goal of 800,000 indicates an allowable harvest of 57.2%. As seen in the Appendix, the Naknek and Kvichak stocks are harvested in the Naknek-Kvichak district, however a Naknek section has been established to allow additional protection or harvest on the Naknek stocks. The desired harvest rate of 72.3% on the Kvichak run indicates a substantial differential harvest rate between the two stocks. Should the Kvichak inshore run return as predicted, the greater harvest rate on the Kvichak stocks may require additional protection for the Naknek run.

Table 9. Naknek River Red Salmon Smolt Production Data[1/] 1954-62
Number of Fish in Thousands

Brood Year	Escapement	Smolts Produced	Smolt Per Spawner
1954	799	6,344	7.9
1955	278	2,123	7.6
1956	1,773	12,149	6.9
1957	635	13,153	20.7
1958	278	4,799	17.3
1959	2,232	12,962	5.8
1960	828	16,725	20.2
1961	351	11,112	31.7
1962	723	12,127	16.8

1/ Data Sources: a.) Alaska Department of Fish and Game, 1965

b.) Tables provided by DiCostanzo and Jaenicke, Bureau of Commercial Fisheries, USFWS, Auke Bay, Alaska

Table 10. Naknek River Red Salmon Marine Survival 1/ 1956-62
Number of Fish in Thousands

Year of Outmigration	Number of Smolt	Adult Return 2/	Per Cent Survival
1956	6,000	870	14.5%
1957 3/	3,040	4,957	163.1
1958	10,060	2,625	26.1
1959	12,465	758	6.1
1960	6,691	1,561	23.3
1961	5,613	1,476	26.3
1962	16,462	3,800	23.1

Geometric Mean Survival = 17.9%

1/ Data Sources: a.) Ossiander, 1966

b.) Tables provided by DiCostanzo and Jaenicke, Bureau of Commercial Fisheries, USFWS, Auke Bay, Alaska.

2/ Includes 2-ocean and 3-ocean fish only. Corrected for high seas commercial catch.

3/ Omitted as outlier.

Figure 16. Naknek River Red Salmon Escapement - Smolt Production Relationship, 1954-62

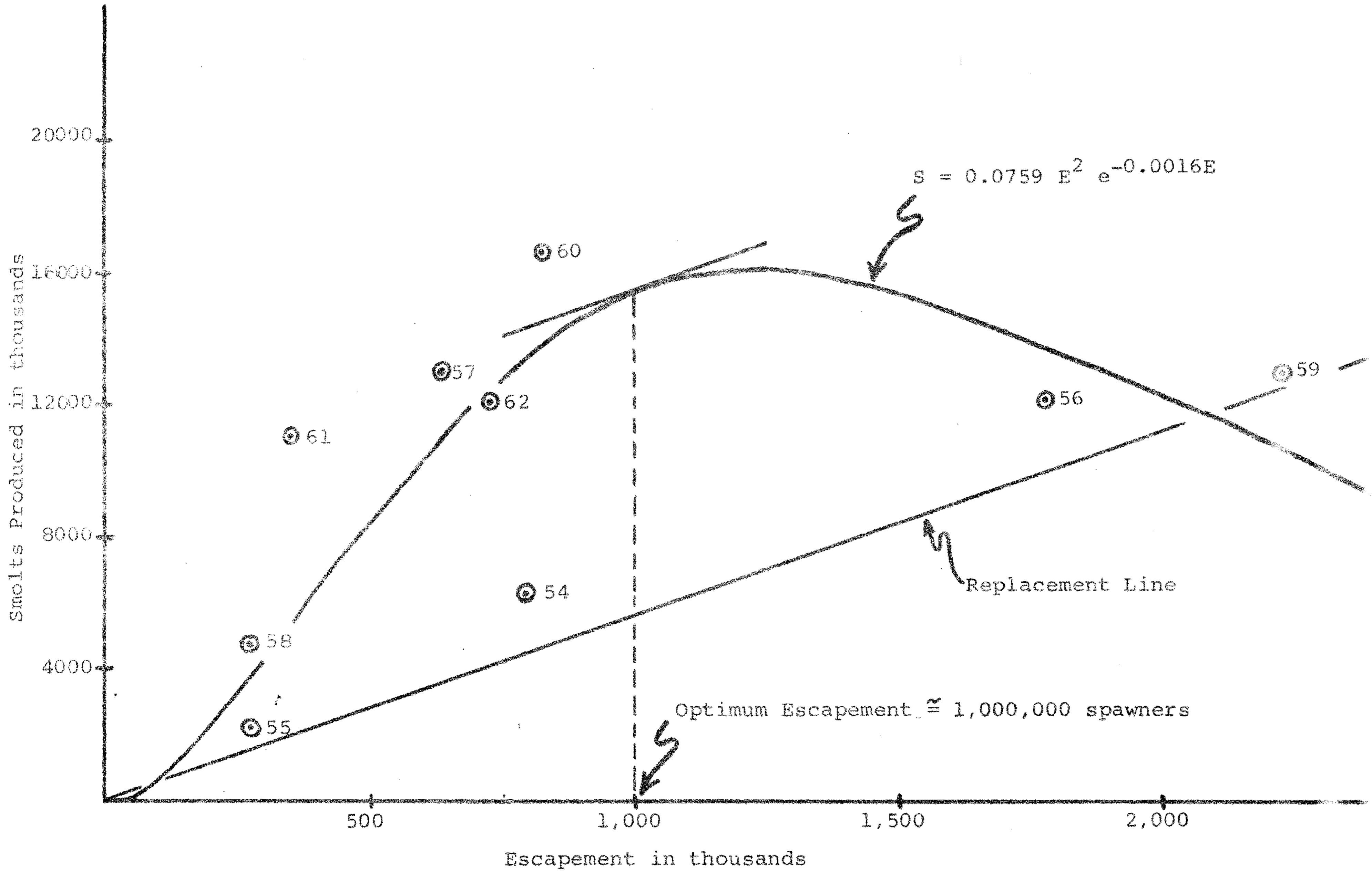
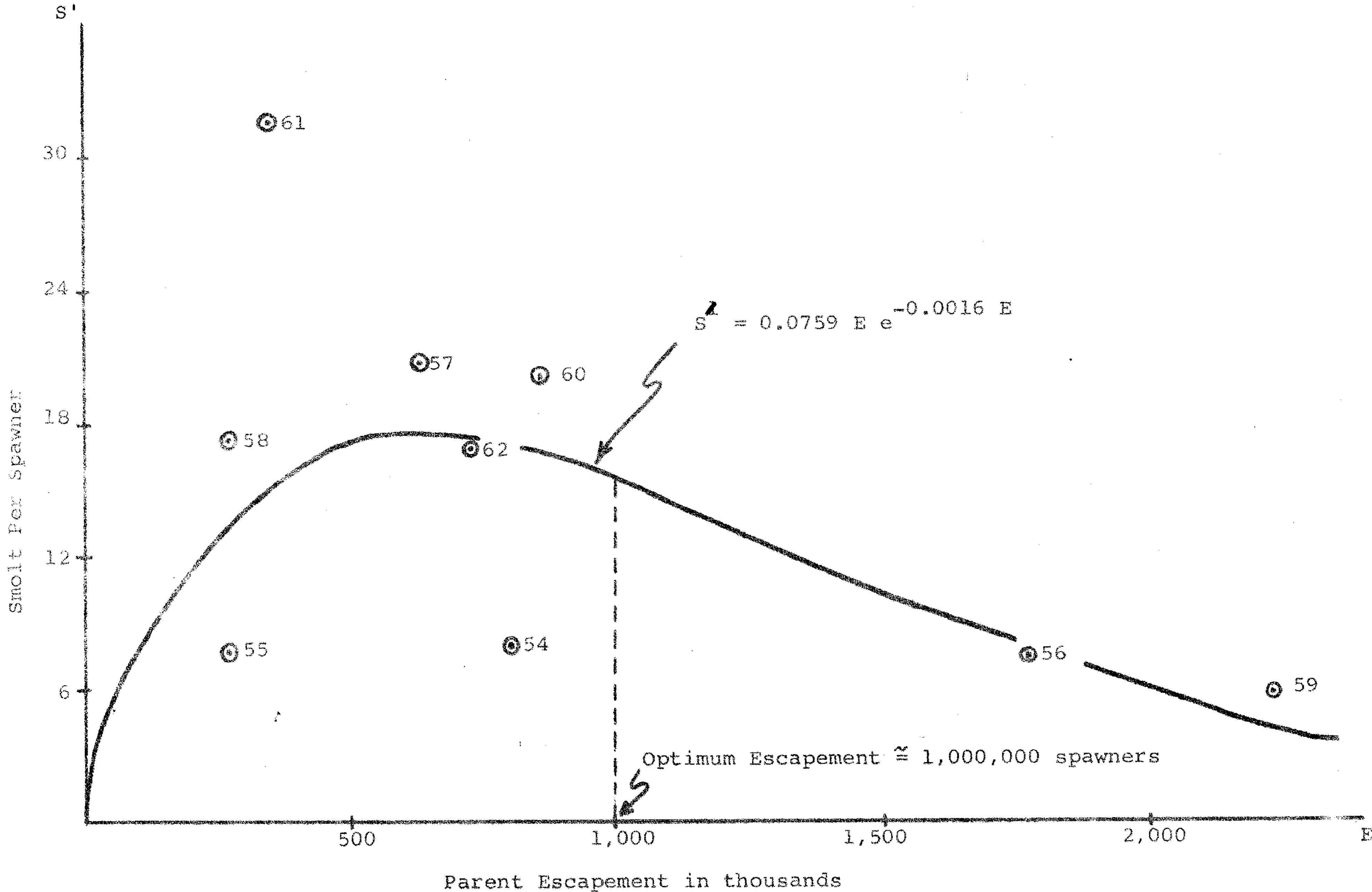


Figure 17. Naknek River Red Salmon Escapement - Relative Smolt Production Relationship, 1954-62



BRANCH (ALAGNAK) RIVER

1966 Prediction: 191,000

1966 Escapement Goal: 53,000

1966 Escapement Range: 50,000-100,000

Escapement-return data for the period 1955-59 is given below in Table 11. As shown in the Appendix, the Branch River stocks are harvested in the Naknek-Kvichak commercial fishing district. Since the Kvichak and Branch River runs are integrated as they pass through the fishery and because of the predominance of Kvichak fish, this district must be managed primarily for the Kvichak run. Therefore, Branch River fish are only harvested incidentally to the Kvichak run. The anticipated harvest rate of 72.3% on the Kvichak stocks indicates that approximately 138,000 Branch River sockeye will be harvested while the commercial catch is being procured from the Kvichak run. This leaves approximately 53,000 fish as escapement to the Branch River.

Cursory examination of the production data of Table 12 indicates that optimum production will probably be realized by escapements in the range of 600,000-800,000 spawners. Escapements to this system have averaged 343,977 sockeye for the period 1957-65. Obtaining maximum production from this system will be extremely difficult since these stocks cannot be managed independently of the Kvichak runs.

Table 11. Branch River Red Salmon Escapement-Return Data 1/, 1955-60.
Number of Fish in Thousands

Brood Year	Escapement	Return	Return Per Spawner
1955	166	1,208	7.3
1956	785	2,360	3.0
1957	125	83	0.7
1958	91	167	1.8
1959	825	830	1.0

1/ Data source: Ossiander, 1966

EGEGIK RIVER

1966 Prediction: 3,175,000

1966 Escapement Goal: 1,000,000

1966 Escapement Range: 800,000-1,200,000

The only data available for the Egegik system is escapement-return data for 1944-58. Smolt studies originally begun in 1955 were discontinued in 1956 after it was discovered that the major portion of the smolt migrate during spring break-up making it impossible to obtain a quantitative index of outmigration.

Escapement-return data from 1944-58 for the Egegik system is given in Table 12. Figures 18 and 19 show the production and relative production respectively plotted against escapement. No attempt was made to fit production curves to this data. It should be noted that two different levels of relative production occurred - a low level (1.0 -3.1 return per spawner) for the years 1944-53, and a higher level (4.5-6.4 return per spawner) for the years 1954-58. This apparent difference in relative production may be related to the fact that prior to 1953, annual spawning population were estimated on the basis of aerial surveys of the spawning grounds. Over-estimating the escapements during the period 1944-52 would result in this apparent lower rate of relative production. This does not explain the low production for the year 1953.

Although returns are not complete for the years 1959 and 1960, on the basis of available data (inshore returns and 1966 prediction) it appears that 1959 will fall in the range of low relative production while 1960 will fall in the higher range of relative production, with the return from 1960 very probably equaling the return from the 1956 brood year. If this is the case, with the 1956 escapement of 1.1 million and the 1960 escapement of 1.8 million spawners, this would indicate a leveling off of production somewhere in the range of 1-2 million spawners.

Escapements to the Egegik system have increased during the past seven years. From 1952 to 1958 the average escapement was 542,307, increasing to 1,127,433 during the last seven years, 1959-1965.

Aerial surveys of the major spawning areas in Becharoff Lake during peak spawning have indicated that sufficient spawning areas exist for spawning populations of at least one million fish.

On the basis of the above considerations and in view of the predicted return of 3,175,000 the 1966 escapement goal has been set at 1 million with a range of 800,000-1,200,000. The above prediction and escapement goal would represent a 68.5% allowable harvest of sockeye in 1966.

Controlled escapement into the Egegik system is somewhat more difficult due to the absence of any bay where the buildup of fish may be detected and the resultant speed with which the fish move through the small fishing district. Immediate escapement estimates can not be obtained from aerial surveys because of the turbid river water which extends to just below the outlet of the lake. On the basis of test fishing data, fish passing through the fishery require 6-7 days to reach the counting tower at the outlet of Becharoff Lake. In spite of these difficulties, management has been able to obtain escapement goals with a relatively high degree of success through the use of test fishing and continuous aerial observations of the clear water lagoon at the lake outlet.

Table 12. Egegik River Red Salmon Escapement-Return Data[1/], 1944-58
(Number of fish in Thousands)

Brood Year	Escapement[2/]	Return	Return per Spawner
1944	310	630	2.0
1945	530	561	1.1
1946	660	1,296	2.0
1947	910	2,075	2.3
1948	890	2,425	2.7
1949	920	961	1.0
1950	630	1,367	2.2
1951	950	2,953	3.1
1952	757	1,276	1.7
1953	519	1,180	2.3
1954	507	2,288	4.5
1955	271	1,355	5.0
1956	1,104	7,059	6.4
1957	391	2,288	5.9
1958	246	1,283	5.2

1/ Data Source: Ossiander, 1966

2/ Methods of estimating escapement: Aerial Survey, 1944-52
Weir 1953-56
Tower 1957-60

Figure 18. Egegik River Red Salmon Escapement-Return Data, 1944-58.

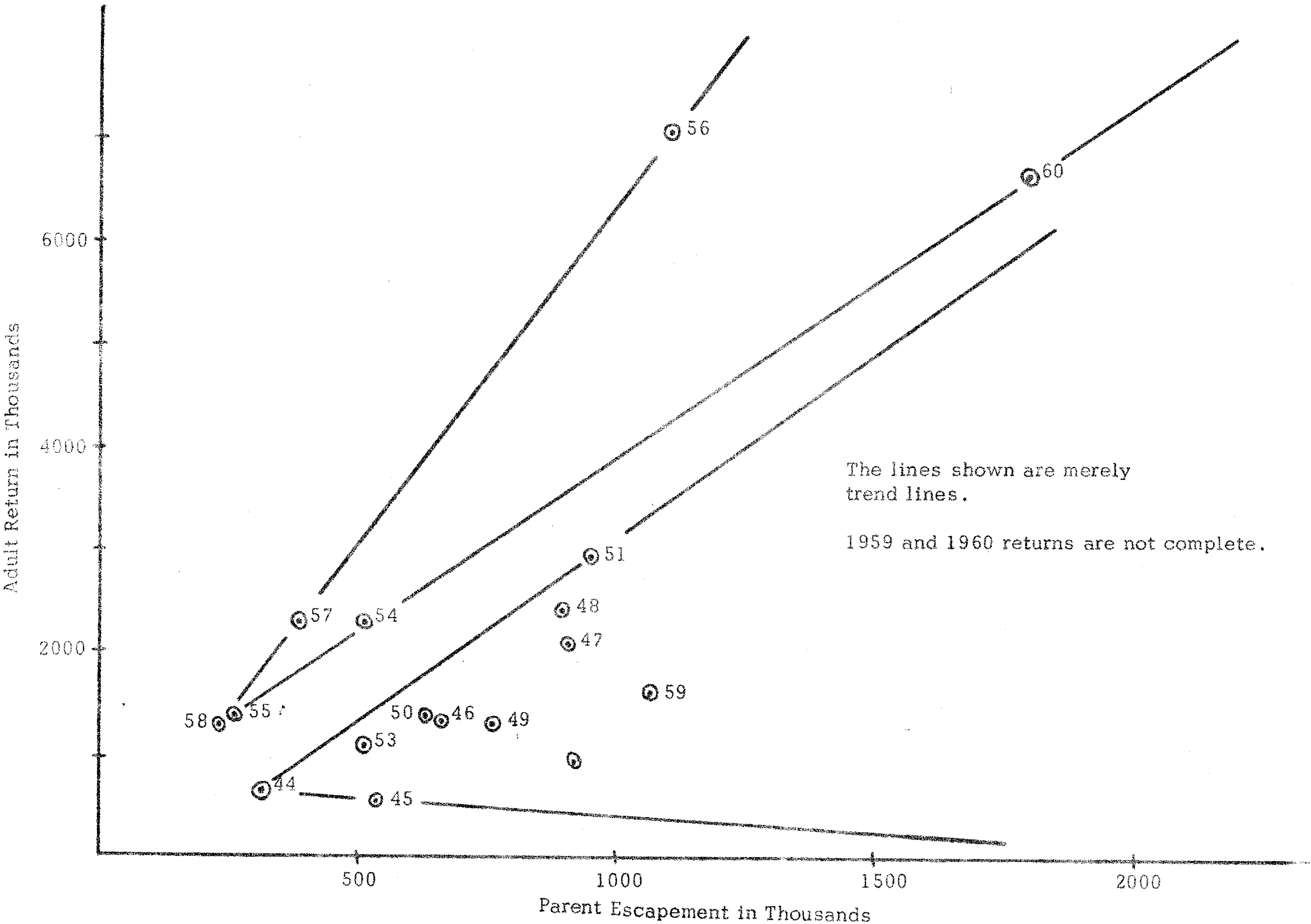
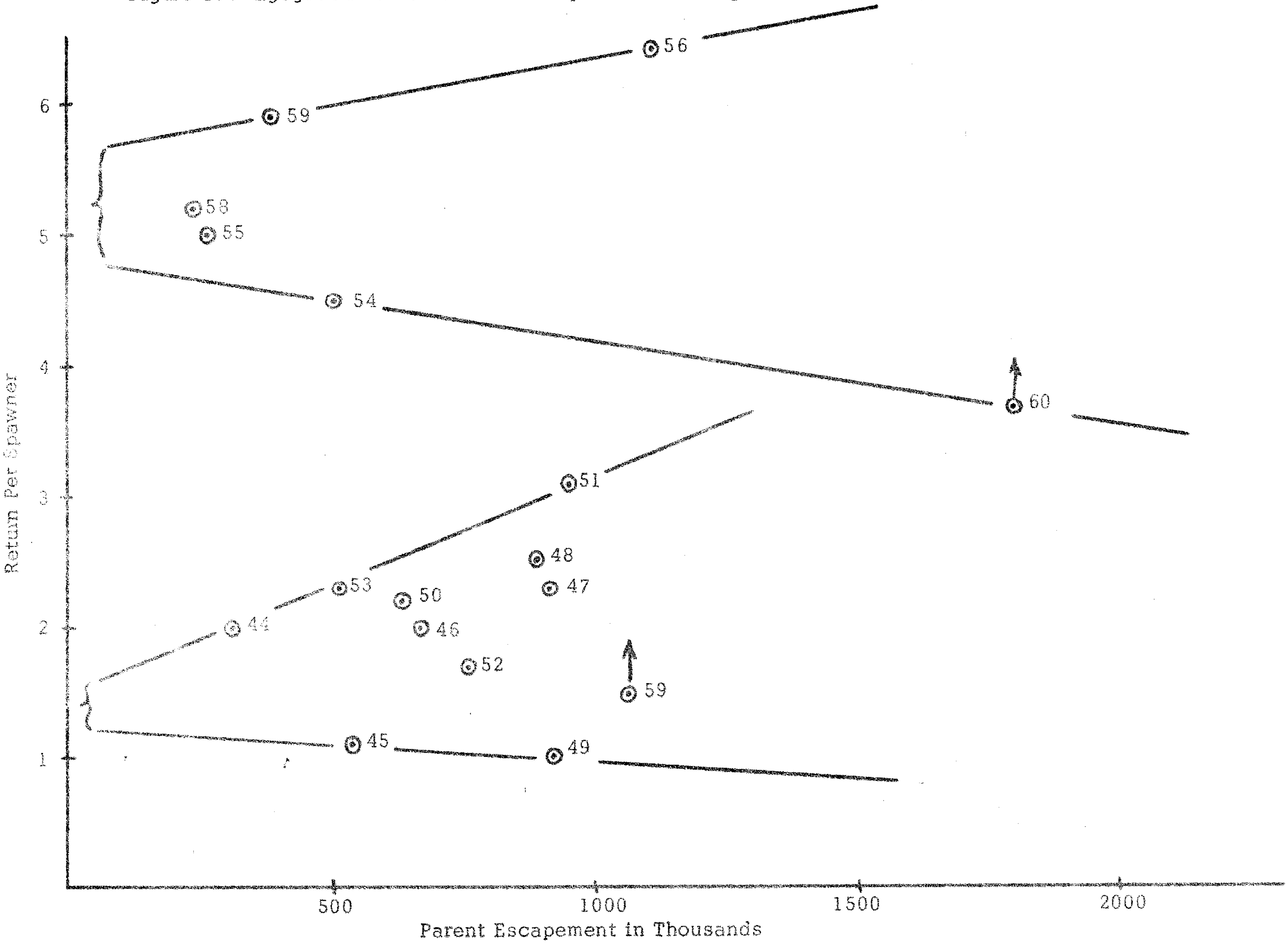


Figure 19. Egegik River Red Salmon Escapement-Relating Production Data, 1944-58.



UGASHIK RIVER

1966 Prediction: 1,230,000

1966 Escapement Goal: 850,000

1966 Escapement Range: 700,000-1,000,000

Smolt studies have been conducted on the Ugashik system since 1956, however, quantitative estimates of the outmigration were not obtained until 1958. For purposes of comparing production from each year, Table 13 shows smolts produced by brood year for the years 1955-62. The relative production (i.e. smolts produced per spawner) for each brood year is also given.

For the years 1955-62, all escapements were less than 500,000 with the exception of 1960 when 2,304,200 sockeye were counted past the tower. The general trend in the Ugashik system is for increased production with increased escapement, however, the 1960 brood year does not follow the same trend as the smaller years. This is apparent when comparing relative production by brood year as 1960 shows the second lowest relative production for this period. (The smallest escapement of 80,000 in 1955 reflects the lowest relative production).

Analysis yielded a coefficient of determination $r^2 = 0.895$ indicating that 89.5% of the sum of squared deviations of $\ln S/E^2$ is explained by the regression. The following equation is used to describe the smolt production of the Ugashik system:

$$S = 0.1387 \; E^2 \; e^{-0.0013 \; E} \qquad (10)$$

Figures 20 and 21 show the corresponding curves fitted to the production and relative production data respectively. Assuming a marine survival rate of 13.7% (cf Table 14), an optimum escapement of approximately 1.40 million spawners is indicated.

Escapements to the Ugashik system have been fairly consistent from 1951-65. Average escapement during this period was 563,079 with only three years being in the range of 1 million or greater. The years 1953, 1960 and 1965 had escapements of 1,056,361, 2,341,400 and 996,612 spawners respectively. Omitting these years results in an average escapement of 337,651 sockeye for the same period.

Only a very slight trend for the larger smolt outmigrations to consist of smaller fish and spawning ground surveys indicate that spawning grounds rather than nursery potential may be the factor which limits production in the Ugashik system.

In view of the 1966 prediction of 1,230,000 sockeye, the escapement goal of 850,000 represents a 30.9% allowable harvest. This relatively low anticipated harvest rate reflects 1) an attempt by the managing agency to obtain larger escapements in this system which in recent years (with the exception of 1965) has received escapements somewhat less than that desired, and 2) the large catch anticipated for the Naknek-Kvichak district which will provide some relief for the anticipated low harvest in the Ugashik district. Furthermore, there are some indications that the 1966 Ugashik run will be larger than predicted. To date, the 2.3 million escapement in 1960 has produced only 2.6 million salmon, i.e. the escapement has just barely reproduced itself. Even in view of an anticipated 0.6 million return of 6_3 fish in 1966, this would represent a relative production rate of only 1.4 returning adults per spawner. Because of the relatively large smolt outmigration in 1963 (Age II smolt from the 1960 brood year), the fyke nets may have become saturated, the smolt outmigration under-estimated, and hence a somewhat minimum prediction of the production of 6_3 fish may have resulted.

Therefore, if the return is stronger than anticipated, additional harvest will be allowed.

Table 13. Ugashik River Red Salmon Smolt Production,[1] 1955-62
Number of Fish in Thousands

Brood Year	Escapement	Smolts Produced	Smolt Per Spawner
1955[2]	77	496	6.4
1956	425	11,805	27.8
1957	215	4,683	21.8
1958	280	6,312	22.5
1959	219	3,997	18.3
1960	2,304	31,595	13.7
1961	349	17,605	50.4
1962	255	10,594	41.5

1/ Data Source: Letter from Mike Nelson, 8/31/65.

2/ Age I smolt from the 1955 brood year estimated on the basis of returning adults and average marine survival.

Table 14. Ugashik River Red Salmon Marine Survival[1/] 1958-62
Number of Fish in Thousands

Year of Outmigration	Number of Smolt	Adult Return[2/]	Per Cent Marine Survival
1958	11,660	4,084	35.0%
1959	2,887	257	8.9
1960	5,504	623	11.3
1961	3,802	565	14.9
1962	16,692	1,519	9.1
		Geometric Mean Survival =	13.7

1/ Data Sources: a.) Letter from Mike Nelson, 8/31/65.
b.) Ossiander, 1966

2/ Includes only 2-ocean and 3-ocean fish. Corrected for high seas commercial catch.

Figure 20. Ugashik River Red Salmon Escapement - Smolt Production Relationship, 1955-62

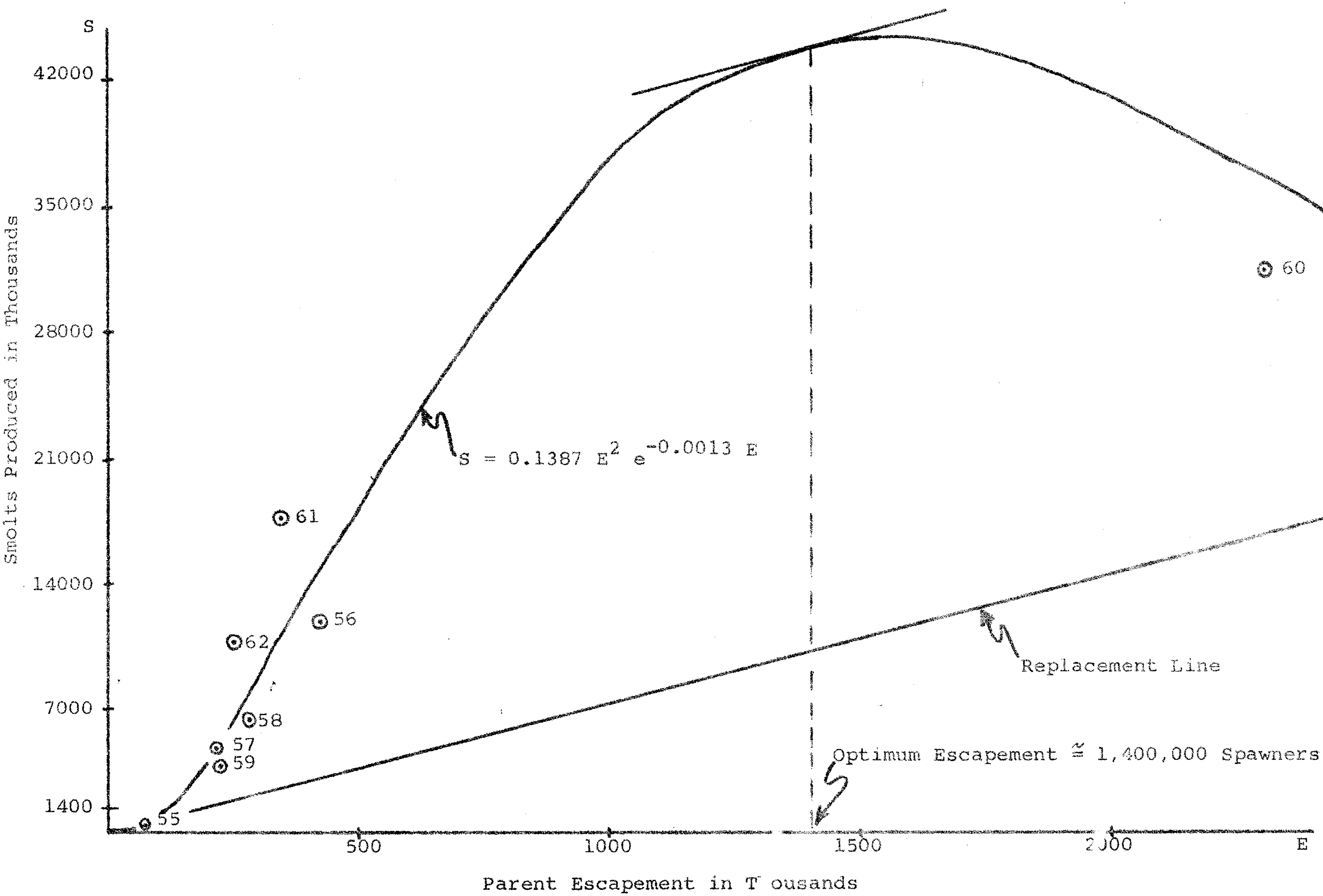


Figure 21. Ugashik River Red Salmon Relative Production Relationship, 1955-62

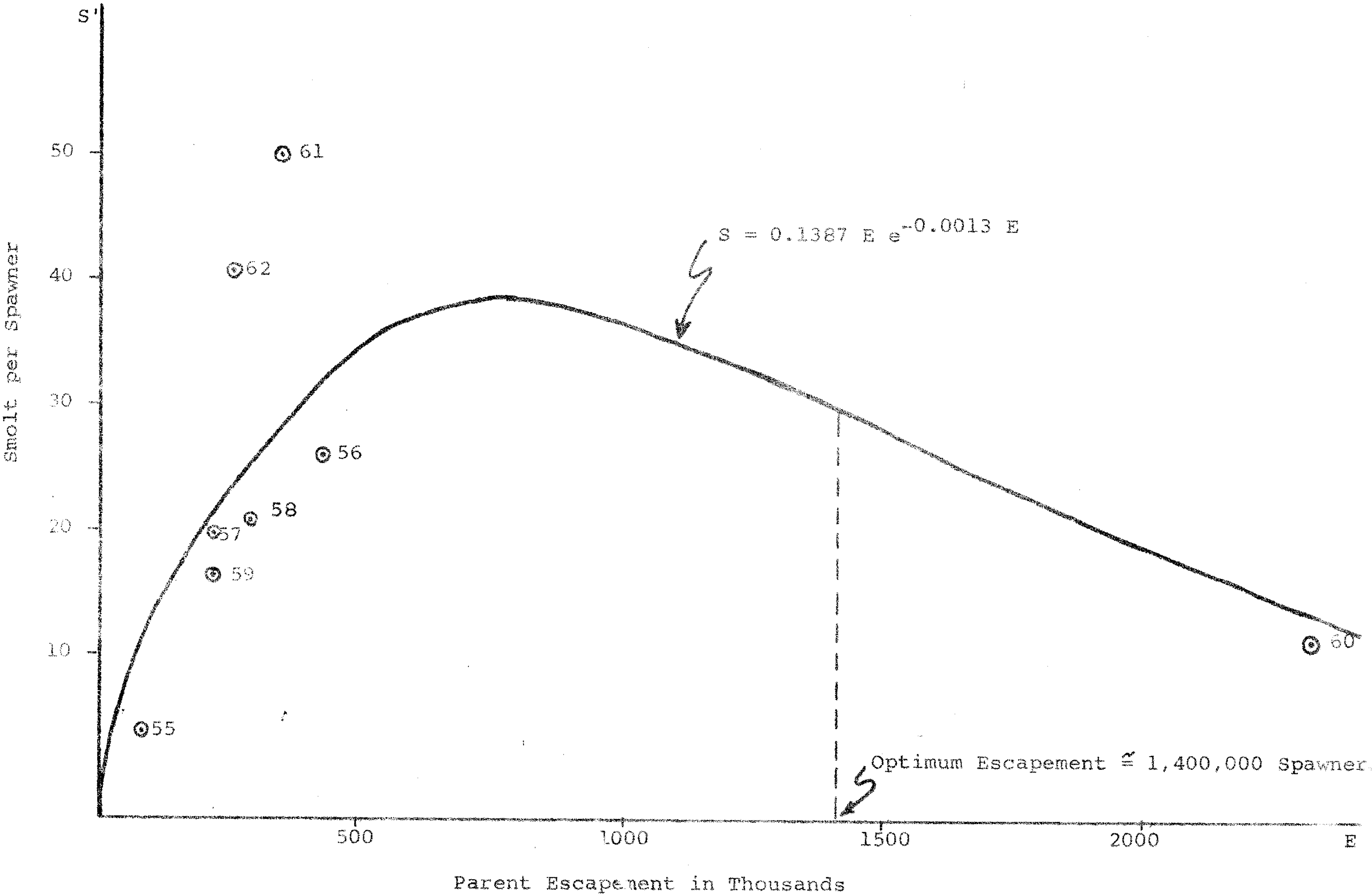


Table 15. 1966 Bristol Bay Red Salmon Escapement Goals by River System

River System	Prediction	Escapement Goal	Estimated Harvest	Percent Harvest
Wood River	2,416,000	900,000	1,516,000	62.7
Igushik River	553,000	200,000	353,000	63.8
Nuyakuk River	241,000	150,000	91,000	37.8
Snake River	11,000	11,000	0	00.0
Nushagak & Mulchatna	47,000	20,000	27,000	57.4
Total Nushagak	3,268,000	1,281,000	1,987,000	60.8
Togiak River	313,000	120,000	193,000	61.7
Togiak Tributaries 1/	30,000	15,000	15,000	50.0
Kulukak River 1/	10,000	5,000	5,000	50.0
Total Togiak	353,000	140,000	213,000	60.3
Kvichak River	21,638,000	6,000,000	15,638,000	72.3
Branch River	191,000	153,000	138,000	72.3
Naknek River	1,867,000	800,000	1,067,000	57.2
Total Naknek-Kvichak	23,696,000	6,853,000	16,843,000	71.1
Egegik River	3,175,000	1,000,000	2,175,000	68.5
Ugashik River	1,230,000	850,000	380,000	30.9
Total Bristol Bay	31,722,000	10,124,000	21,598,000	

1/ These predictions are based on average returns to these systems.

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Figure A-1. 1966 NUSHAGAK COMMERCIAL FISHING DISTRICT.

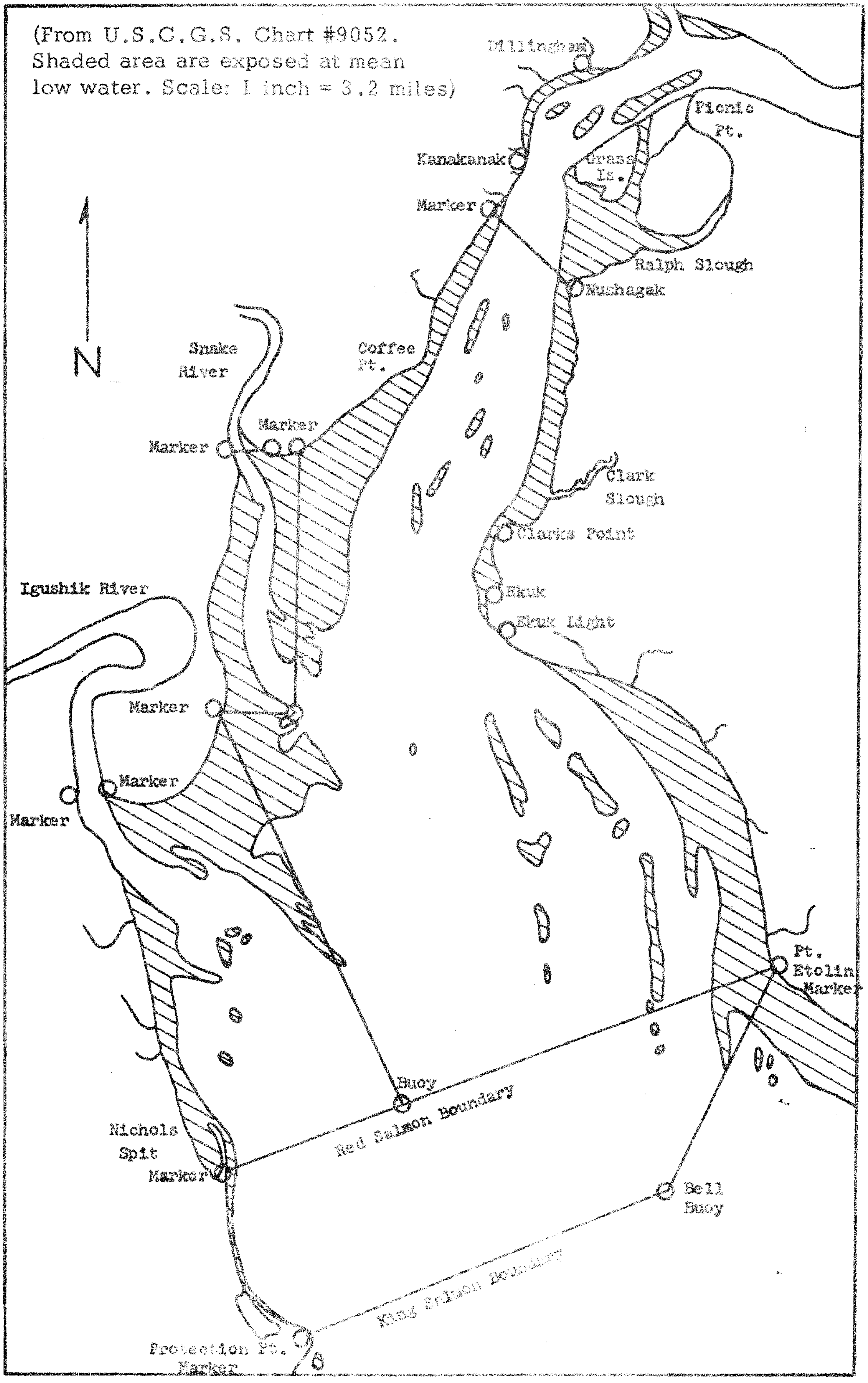

Figure A-2. 1966 TOGIAK COMMERCIAL FISHING DISTRICT

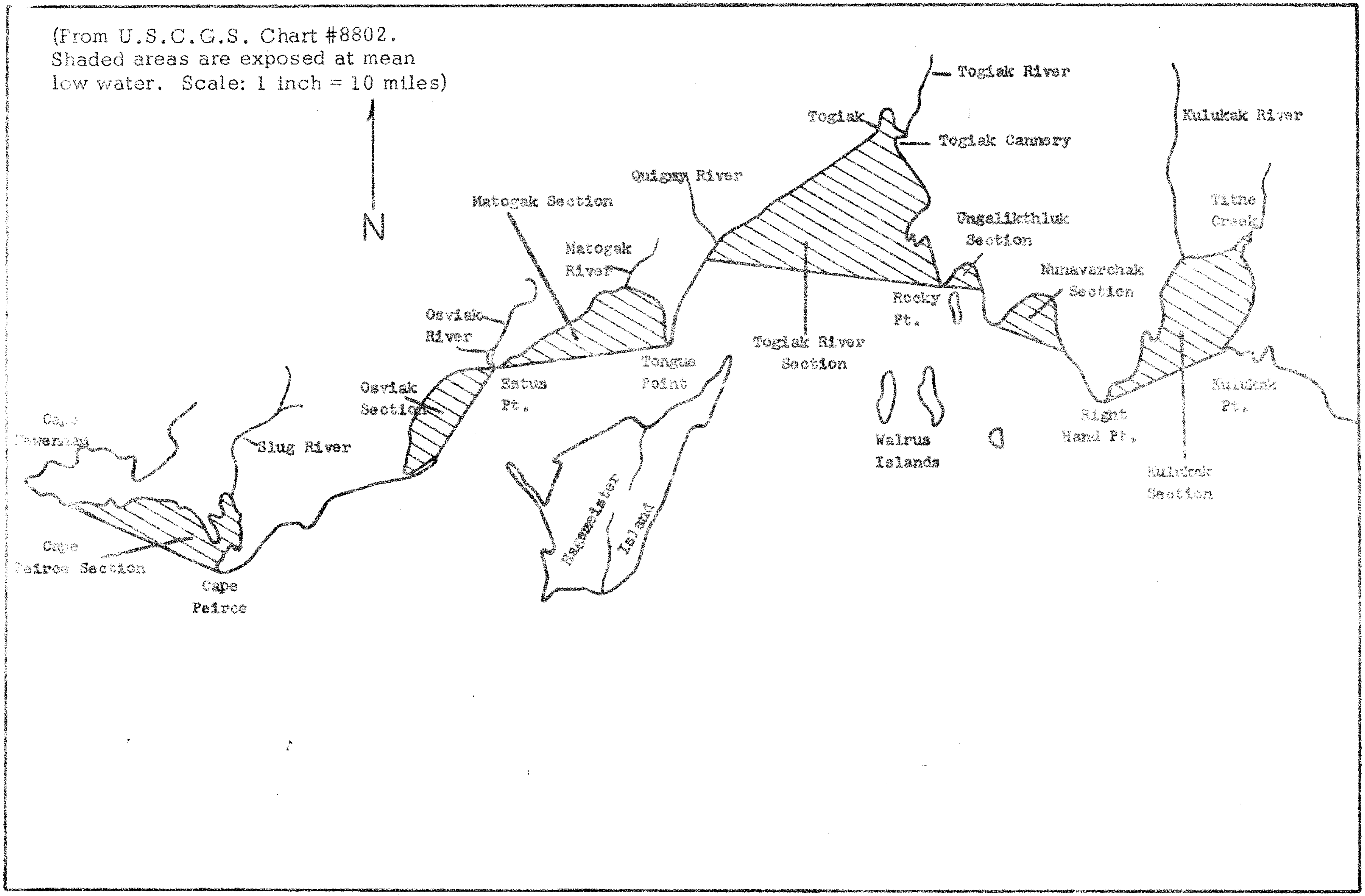

Figure A-3. 1966 NAKNEK-KVICHAK COMMERCIAL FISHING DISTRICT

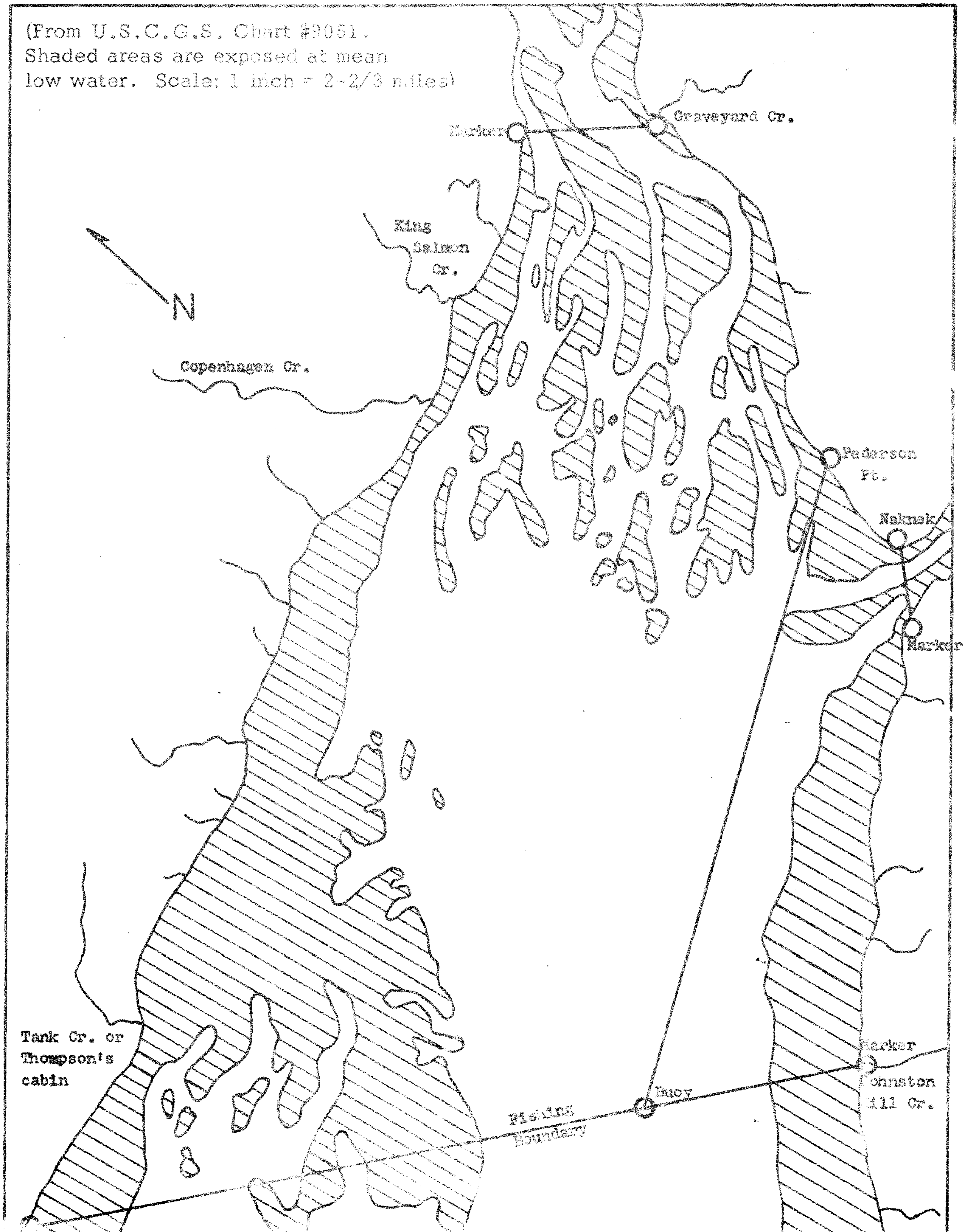

Figure A-4. 1966 EGEGIK COMMERCIAL FISHING DISTRICT

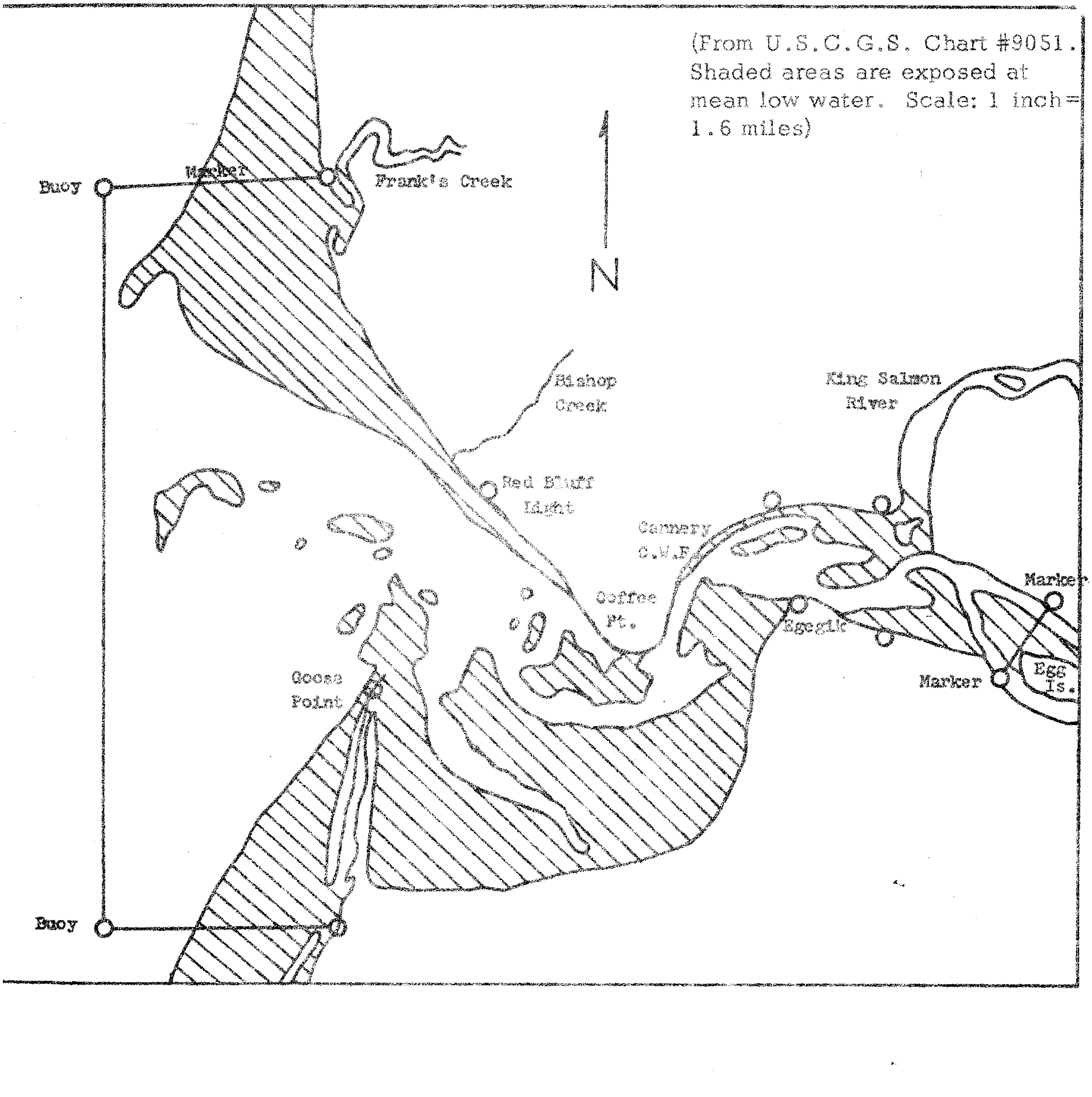

Figure A-5. 1966 UGASHIK COMMERCIAL FISHING DISTRICT